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FOURTH TRIPARTITE CONFERENCE ON ARMY OPERATIONAL RESEARCH 1953

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FOURTH TRIPARTITE CONFERENCE ON OPERATIONAL RESEARCH

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THE FOURTH TRIPARTITE CONFERENCE

on

ARMY OPERATIONAL RESEARCH

held in

SHRIVENHAM and LONDON

30 August - 5 September, 1953

The Fourth Tripartite Conference on Army Operational Research was convened by the War Office, and was attended by delegates representing the Army Operational Research Agencies and Army Staffs of Canada, the United States, and the United Kingdom.

The programme included two major and nine minor technical discussions held at the Royal Military College of Science, Shrivenham, and three formal presentations and a policy meeting of eleven senior delegates representing the three nations, held in London.

The U.K. delegates were the hosts at this conference. Ours was the pleasure of welcoming our overseas colleagues; ours, also, the duty of preparing a record of the proceedings of the conference. This report represents our fulfilment of that duty, and gives, we hope, a true and complete account of the proceedings.

THE DELEGATES

The delegates to the Conference were:-

United States	Canada	United Kingdom
Dr. Lynn H. Rumbaugh: Leader	Col. C.R. Boehm: Leader	Mr. H.A. Sargeaunt: Leader
Dr. H. Cole	Col. G.M. Carrie	Mr. C. Barham
Dr. S.W. Davis	Mr. I.H. Cole	Mr. D.F. Bayly Pike
Miss G. Donovan	Dr. T.W. Cook	Mr. E. Benn
Dr. G. Gamow	Mr. T.K. Groves	Mr. R.W. Brittain
Lt. Col. H.E. Gould	Mr. G.D. Kaye	Mr. S.W. Coppock
Dr. J.B. Green	Dr. A.C. Lauriston	Lt. Col. Davis-Scourfield
Dr. L. Hawkins	Maj. F.G.B. Maskell	Lt. Col. G.W.H. Fellows
Mr. J.H. Henry	Mr. J.E.D. McCord	Lt. Col. R.H. Fletcher
Mr. B. Marshall	Dr. N.W. Morton	Mr. G.N. Gadsby
Brig. Gen. S.L.A. Marshall	Maj. J.S. Orton	Mr. P.J. Geeson
Dr. D. Meals	Dr. A.J. Skey	Mr. A.H. Gould
Mr. A.H. Moore		Mr. R. Gye
Lt. Col. D.E. Munson		Mr. B.D. Hankin
Dr. T. Page		Mr. W.H. Hill
Col. E.M. Parker		Mr. L.J. Holman
Dr. E. Paxson		Mr. R.W. James
Col. D. Tredennick		Major M.P. King
Dr. J.K. Tyson		Mr. A.W.R. Lockwood
Dr. M. Vigneras		Lt. Col. V.H.B. Macklen
		Mr. S.H. Mound
		Mr. H. Murray
		Mr. F.J. Nash
		Mr. J. Newsome
		Lt. Col. C.R. Nicholls
		Maj. D. Norman
		Mr. J.D. Oates
		Dr. J. Redfearn
		Mr. M.I. Rickers
		Mr. A.W. Ross
		Dr. I.J. Shaw
		Mr. R. Shephard
		Mr. E.G. Smith
		Mr. G.S. Stewart
		Mr. G. Wooldridge.

In addition to the above delegates, we were pleased to welcome to our discussions the Chief Scientist of the Ministry of Supply, Dr. O.H. Wansborough-Jones, the Quarter-Master-General, General Sir Ouvry Roberts, the Commandant of the Royal Military College of Science, Maj. General Davey and members of his staff.

RECORD OF CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

1. At the end of the Conference, senior delegates from each of the three countries met to discuss the conclusions and recommendations arising from each of the technical sessions held. The following are the conclusions and recommendations drawn up by the senior delegates. The Conclusions represent the main technical points arising out of the discussions, while the Recommendations contain the points requiring ratification and action by the respective Armies.

GENERAL CONCLUSIONS

2. The senior delegates noted that each party had derived great benefit from previous Tripartite Conferences and that considerable progress had been made on action recommended at the Third Tripartite Conference held in Kingston and Ottawa in the spring of 1952. The Fourth Tripartite Conference had been highly successful in stimulating new ideas and in assisting the exchange of information, and was greatly assisted by the excellent facilities made available by the Royal Military College of Science. It was agreed that there is a continuing need for periodic conferences.

3. It is desirable that continuity be provided between Tripartite Conferences on Operational Research by the early exchange of proposed agenda and by intervening meetings of small representative planning groups.

4. The topics for discussion at the next Tripartite Conference should include the effects of atomic and other new weapons on military organisation and tactical doctrines.

5. It is still considered that valuable contributions could be made by an operational research group at SHAPE as recommended by the Third Tripartite Conference.

6. There is a critical and growing shortage of personnel trained in operational research techniques in all three countries. Ways and means should be supported to attract capable young men and women into the field of operational research, and to give them the necessary breadth of experience to work effectively.

SUMMARY OF THE PRINCIPLE CONCLUSIONG OF THE WORKING PARTIES

7. The present procedure for handling tactical intelligence is too slow for the new weapons. Information should be screened at the lowest practicable level and passed direct to action level.

8. Further study is required to determine in what degree the present time delays in overall transmission and processing of military information limit the control and mobility of fighting forces, and how these limitations can be removed.

9. All-weather methods of collecting tactical intelligence, which are selective to important targets, are required to supplement photographic reconnaissance to reduce the demands for bulk photographic cover. In addition, improved means are needed for the rapid identification of important targets on photographs.

10. The increased complexity of modern communications equipment, and the resulting maintenance load, are matters of widespread concern. The relation between causes of failure and consequent communications delays needs further study, together with the economics of sub-assembly replacement versus existing maintenance methods.

11. Increased attention should be paid by army operational research agencies to the organisation and conduct of war games.

12. Low level air attack appears to be a major threat, but the magnitude of this threat to the Allies needs more study before the best means of defence can be assessed.

13. The vulnerability of Army logistics systems to attack by conventional weapons, by new weapons and by special forces requires further study to evolve the best means for attack and defence.

14. Studies of guerrilla warfare in active areas show both the great importance of this type of warfare and the need for collecting as much information as possible during hostilities in several different areas.

15. There is a need for continued studies in the field of fatigue and stress, leading to the correlation between physiological and psychological tests on the one hand, and military effectiveness on the other. Simulation of realistic stresses appears to be practicable in the exposure of troops to rigorous environment during exercises in the arctic, in the tropics, or in mountainous terrain.

16. The present methods of studying small-unit infantry actions through battlefield surveys, combat records and training exercised are limited in value and should be supplemented by after-action interviews and specially designed exercises.

17. In order to facilitate plans for the optimum use of our several manpower resources, it is desirable that each of the three countries formulates its military manpower requirements and potentialities in the same - or comparable - technical terms.

RECOMMENDATIONS

18. The following recommendations have the concurrence only of the official Army Operational Research Agencies of Canada, the United States and the United Kingdom represented at the Fourth Tripartite Conference, and are subject to notification by the respective Army Staffs.

19. The United Kingdom should investigate the possibility of incorporating a PHANTOM Signals Regiment in a major exercise which could be studied by a Tripartite Operational Research team.

20. Both the short-term exchanges of technical personnel between the three Army Operational Research Agencies and the assignment of personnel for combined operational research studies in overseas theatres have produced fruitful results and should be continued.

21. At further Tripartite Conferences on Operational Research properly cleared delegates should be encouraged to discuss the impact of atomic weapons on military tactics and organisation, without including technical details excluded by National laws and policies.

22. The fifth Tripartite Conference on Operational Research should be held with the United Stated as host nation during the autumn or late summer of 1954.

23. This document should be filed with the Primary Standardization Office for pruposes of recording the conclusions and recommendations set forth above after ratification of the recommendations by each Army Staff.

(Sgd) C.R. Boehm,
Colonel, Chairman
Canadian Delegation

(Sgd) H.A. Sargeaunt,
Scientific Adviser
to the Army Council

(Sgd) L.H. Rumbaugh,
Deputy Director
Operations, Research
Office U.S. Army

OPENING SPEECHES

The Conference began on Monday, 21st August, with opening speeches by Maj. Gen. Davey, Commandant, Royal Military College of Science, Mr. Sargeaunt, Dr. Rumbaugh, and Col. Boehm, leaders respectively of the UK, US and Canadian delegations.

Maj. Gen. Davey:

"Dr. Rumbaugh, Col. Boehm, Mr. Sargeaunt, Gentlemen: The College is very privileged to have you here. We are delighted that you have chosen this venue to carry out your conference and it gives me, personally, great pleasure on behalf of the Staff of the College to welcome you here and we hope that your conference will be a great success. Our job, of course, is like Mr. Butlin's, - to provide you with bed, breakfast, lunch, tea and to see that you are as comfortable as possible. This is more or less the limit of our responsibility, though of course you very kindly asked us to attend some of your deliberations, and these will be of tremendous interest to me and my staff. But I hope that we have done all you require and could wish for in the way of amenities and the ordinary comforts of life, and if I may say, I hope that this conference will make its contribution towards concord and accord between the three countries, and that your deliberations will add to your general pool of knowledge.

While you're here, I think you might find it of interest during what you might call your drinking hours, to discover something about this place, because I think it is of interest particularly to the Americans and Canadians - the Americans first of all. Shrivenham was the American University for several months during the latter part of the war, giving members of the Armed Forces a flying start back into civil life. You might be interested to find out something of what went on and what we were trying to achieve.

Our job here is to give the Regular Officer who has the necessary mental capacity a university education to degree level in science or engineering. It is rather a new departure because both in the United States and in Canada you use, as far as I know, your civilian universities for this purpose. And so do we, to some extent - we send some of our Regular Officers to Cambridge - but the majority, and a growing number, come here. We have been doing this for only a few years, and those of you who are interested in education and training might like to see how the plan is working out. In addition, we have our post graduate courses which are more specialised in nature.

We have many Canadians here and we are very glad to see them. I, myself, am particularly happy to welcome them because I am still a member of the Canadian Army and was an instructor at RMC which was their base.

This is all, gentlemen, and thank you."

Mr. Sargeaunt:

"General Davey, Gentlemen: I would first like to thank General Davey very much for having us here. That these conferences should be held somewhere outside the capital city, and if possible, at some place like the Royal Military College of Science, is a change which, I think, the Canadians first introduced. My own view is that this was a great success last year in Canada, and we have now followed this innovation. We have been most fortunate in being invited to hold our conference here at the Royal Military College of Science.

This is the fourth meeting in this series of Tripartite Conferences. The first three necessarily had a certain amount of publicity because in each case it was the first of its kind in the country concerned. This conference is the second to be held in the UK and we have felt that it can therefore be, so to speak, more private, more domestic and more at the 'working level'. We hope that the younger delegates who have done much of the work, will speak as much as possible.

I think our last three conferences have had only qualified success. Looking back, I'm practically sure that wherever discussions have been long and not particularly helpful, the reason has been that the three countries have worked from such different assumptions. Therefore I think that it is

worth while for the chairmen to remember, as far as possible, that the strategic, political, and sometimes even the tactical doctrines of the three countries are different. I would suggest that the chairmen should watch this point, and be ready to stress it when, in the working parties, dissentient opinions, obviously stemming from this source, are voiced.

On our own side, there are only three major points which I should like to bring to your notice. The first is that the British Army has handed over to the RAF the responsibility for the ground to air guided weapon. This does not, of course, apply to the ground to ground guided weapon, nor to the use of the guided weapon for the defence of armies in the field, but it does apply for the home base.

The second point concerns air transport. At the moment, the British Army does not have much air transport of its own. But we do make the fullest use of our huge commercial air charter service, and I think I am correct in saying that more British troops are transported by air than by sea. This state of affairs may be changed, not in the sense that we shall not use the charter services but in the sense that the whole question of air transport, which is at present an RAF problem, is likely to become an Army responsibility. Therefore I think that air transport is a legitimate subject for discussion at this conference, although it is not, at the moment, under our control.

The third of these points concerns the field of atomics. As you are aware, there is practically no subject which we discuss in which the impact of atomic warfare is not felt. I feel that we should try to evolve a working rule to cover our difficulties here, and the one I would suggest is this: we should not hesitate to introduce into our discussions data on atomic effects which have already appeared in open publications.

Since our last meeting we have, as was forecast then, increased our operational research abroad. We have had, in the Far East and particularly in Malaya, an opportunity to study certain aspects of war. I am sorry that we have been unable to bring anyone back from those fields to this conference. I hope, however, that in discussion and conversation, you will be able to learn something of the very interesting work which is going on out there.

That is all, gentlemen, that I have to say, and I now have pleasure in asking Dr. Rumbaugh to speak to you."

Dr. Rumbaugh:

"Members of the Fourth Tripartite Conference, and especially our British hosts, may I, on behalf of the American delegation, say how great a pleasure it is to all of us to be here. I, myself, have now been to England, to various military and other meetings, some four times, and I always look forward to coming back. We can, perhaps, see how well the idea of this conference was received in our own country by the fact that we have some 18 delegates here, and that more wanted to come.

I think that these Tripartite Conferences have accomplished a great deal in previous years. One thing that has been recommended by the previous conferences, and which has been put into effect, is the establishment of more field offices. I would like to remind you all that since the last conference, for example, our European office with the US Army at Heidelberg has become an established reality and is now a going concern.

Mr. Sargeaunt has mentioned the problem of atomic warfare and the fact that it does bear on nearly all present day military thinking. I must confess that the solution to this problem has been rather slow in coming but I personally believe that the solution is definitely nearer. For example, I understand that the subject of the passive defence against atomic weapons and of their active use is now passed to some limited extent among the NATO colleagues, and perhaps more of this will come. There is a definite line of demarcation that can, I believe, be implemented after a time, through the policies of the three governments concerned. This is that there are very definite differences between specific weapons and specific means of delivering those weapons, and the information on these points is, for very

good reasons, quite tightly held in each country. But on the other hand, there are a great many general principles which could be used commonly and by all of us equally well. It is for this reason, and because of the fact that secrecy of one kind or another will always be a "bugaboo" of all international groups, that I would propose that perhaps a conference of this kind should put its main emphasis on procedure - how to go about calculating answers, how to make analyses etc. Because if we are scientific people, and if we begin with more or less the same body of facts, surely by using the tools of operational research and by exchangine our knowledge of the proper use of those tools, we shall arrive at comparable answers. It will not then be necessary to apply for access to knowledge the publication of which might be difficult. And yet, on the other hand, I am quite sure that there is enough in the published literature of low security grading to enable all of us, at the moment, to tackle the problem of atomic warfare with some assurance that we could make a realistic analysis. It is a big problem for us all, and I know that, for my own part, progress in working out the aspects of interest to armed groups has been slow. For that reason I think no one should shy away from discussions of methodology. Finally I would like to suggest that perhaps too much emphasis has been placed on security. After all, the unclassified book called "The Effects of Atomic Weapons" published by the U.S. Government Printing Office which has been out now for three years, could furnish data with which one could, within reason, carry out most of the analyses which are pertinent to the application of atomic warfare.

I would like to end by repeating that we are extremely happy to be here and that we look forward to a very profitable conference."

Colonel Boehm:

"Mr. Chairman, General Davey, Gentlemen: On behalf of the Canadian delegation I, too, wish to express our pleasure at being here in these very pleasant surroundings and among such good company. I thought that in my opening remarks I should describe briefly how our Canadian delegation is made up and the work done in the last year. Our delegation represents, through the personnel engaged on it, both the civilian and military aspects of operational research work and it is intended to make the best possible team by the close association of civilian and military members. We find this team-work is very necessary in all our undertakings.

This organisation of operational research work in Canada is in two parts. In the Army part, which we call CAORE - Canadian Army Operational Research Establishment - there is a group in Kingston with military and civilian personnel, and a field team in Korea. Also, (in the same department of National Defence,) the Defence Research Board operates an Operational Research Group. This latter deals with inter-service problems of interest to more than one of the Armed Services as well as acting in support of individual Services in their particular problems. During the past year we have followed very closely the specific subjects contained in the records of agreements and recommendations of the last Tripartite conference. We have worked on the following problems:-

The Army manpower flow problem.

The principles of northern military operations as drawn from the campaign in Finland.

Criteria of weapon effectiveness.

Anti-tank weapons. Methods used for the conduct of trials of these weapons and the evaluation of the trials results.

The performance analysis of the heavy reconnaissance vehicles, based on last war data.

Movements of troops and equipment in a forward area in the face of enemy air superiority.

Assessment of bridging requirements in the field.

The field team in Korea based their operations on the immediate requirements of the Commander of the Canadian Brigade. It dealt with casualties, both battle and non-battle as related to the flow of manpower into the theatre. It also dealt with tank casualties, with the state of training of the Canadian soldier arriving in the Far Eastern theatre, with the organisation and weapons of the Infantry Battalion Support Company, and it co-operated with the US Operational Research Organisation on project WEEVIL. The team also made observations on new equipment and clothing sent for trial purposes to our troops in Korea.

The Defence Research Board, in co-operation with the Armed Services concerned, has undertaken studies of a group of problems affecting the Canadian Mobile Strike Force in its northern operations. The following problems have been studied.

The detection and reporting of enemy activity in northern Canade. Investigations of photographic methods of enemy localisation and assessment.

Indoctrination training for military formations.

Personal and tent group equipment for infantry.

Ground investigation.

The effect of arctic climate on military efficiency.

Tent group sizes for military operations in the north.

Another group has studied the problems of air defence, with particular reference to anti-aircraft guns, fire control equipment, guided missiles, etc., and a third group is making a study of the effect of the use of atomic weapons in the field.

In conclusion, I might say that all the Canadian delegates agree with me in liking the programme and the arrangements made for this conference. We particularly appreciate the benefits of being away from the heavy atmosphere of London and in the more congenial surroundings of the Royal Military College of Science."

Mr. Ross:

"Mr. Sargeaunt, General Davey, Gentlemen: First of all may I add my welcome to the visitors and say that we all hope you have both a very profitable and a very pleasant time while you are here. One of the things that seems to me most interesting is the extent to which the programme of work of ORO, the Canadians and ourselves now agree. In other words, we all agree on what are the important problems for us to study. As a consequence of this, I think we have had singularly little difficulty in choosing the programme for this conference. It is a most interesting programme of subjects, but they are, on the whole, difficult problems, and they are difficult for different reasons. Two of them at least, low level air defence and tactical reconnaissance, are difficult, not because we do not know what we would like - there is no difficulty in stating the requirements - but because the solutions are technically difficult. Then there are other problems, such as training, manpower, signals requirements, air transport etc. for which the best solution cannot be implemented because of a shortage of resources in manpower or money. In these, the problem is slightly different in that we have to find the optimum solution for each country within the limits of available resources. This type of solution is, of course, very suitable for operational research, and here I particularly agree with Dr. Rumbaugh that we should discuss the approach which we are going to adopt towards these problems. It must, however, be remembered that the background situation is so very different, in the three countries, and even if our approach is the same the solutions need not necessarily be identical.

Finally, by general agreement, we have included one more general subject, covering a prediction of the likely form of a future war. This should give scope for the theorists. Everyone can enjoy themselves on games theory, or prediction of time series, and, although this is interesting as a subject in itself, it is also very important practically, because we are trying to deduce the optimum utilisation of our resources for the next war. Unless we have some idea of the likely form of the next war, we cannot say that any solution is satisfactory. The problem of identifying, in a scientific manner, the general trends of warfare is by no means an easy one.

Although the problems on our programme are difficult, this does not mean that they will not give rise to good discussions; but, I am afraid, in most of them no quick answers will emerge. If anything does come out than I shall be delighted, but we should not be too disappointed if we fail to provide answers to some of the problems."

Major Paper

Defence Against Low Flying Aircraft

Mr. Henry:

Before going into this discussion of defence against low level attack, presumably we are more interested in the methods of evaluating the effectiveness of low altitude defences rather than discussing the kinds of weapons that might be used in the defence. Of course it is impossible to separate these two, and if I wander from the evaluation to the discussion of possible weapons, I hope you will forgive me.

It might be of value to define just what time period we are talking about. It's customary, I believe, in certain European defence conferences, to say that we are discussing either the present period, or the period four years from now, or ten years from now, or being more ambitious, even more remote time periods. Perhaps we may be able to agree at the outset that at the present time we don't have an effective low altitude defence, and therefore, I shall confine my remarks to some time, perhaps after '57, in which it might be possible to achieve a defence that might be effective.

Now, ORO, earlier this year, tried to evaluate a number of the weapons which were in the US Army research and development programme. From this and similar types of evaluation, we of course, have determined like everybody else, that this low altitude gap exists.

This leads to the point that, in the US and, I think, in Canada and the UK, we seem to have some reasonable possible solutions for defence against aircraft attacks approaching higher than a couple of thousand feet. We are developing weapons, guided weapons, conventional weapons or rockets, which promise to have a very decent effectiveness at these altitudes above, say, two thousand feet.

The difficulty of the problem is, we don't think that we are prosecuting defence against a low altitude attack to the same extent. Low altitude attack, I would like to define as anything above twenty feet above the ground, up to say one thousand or two thousand feet. So we doubt the wisdom of making these large defensive outlays against higher attacks when, in fact, there is a large gap at the lower altitudes. One might say that if these future type weapons achieve the effectiveness predicted, then the enemy won't carry out more than one attack at altitudes above ten thousand feet. We also perhaps, should divide the problem into whether we are talking about defence of the field army, or defence of the home base in the U.K. or the United States or Canada, as appropriate.

Well, before discussing a little bit of what we've done, it might be as well to outline the weapons that are in the U.S. family of air defence. At the outset, in the guided missile field, we don't have anything in being, nor, in fact, in hardware development suitable for low altitude defence. We have what is known as a HAWK programme, which, in fact, is a duplicated programme, three agencies trying to develop a weapon which will be suitable for low altitude defence. This may be a guided missile - it may not. It's a study programme at present. It may be rockets or perhaps even conventional guns. Also, there's been proposed a long range kind of slow-speed guided missile similar to a drone aircraft which might work out to be profitable.

For conventional types of guns, we have one which is just in the design stage - a 60 millimetre gun of a conventional nature although it does achieve, or it's hoped to achieve a rate of fire of about two hundred rounds per minute. We have another weapon known as the STINGER, which is a 37 millimetre gun which it is hoped will be able to achieve a rate of fire of about five hundred rounds per minute, while two of these 37 millimetre guns would fire about a thousand rounds per minute. Of course, there are still lots of the 40 millimetre and 50 calibre weapons in the U.S. Army at the present time.

Another category is that of the rocket gun, which is sometimes called over here, gun assisted rocket. We have a weapon under development, a 70 millimetre rocket. It is fired from a gun with a rather low muzzle velocity, of the order of a thousand feet per second, and then a rocket motor takes over and builds the velocity up to the order of thirty five hundred to four thousand feet per second. It is of unique design, this weapon; it is believed that a rate of fire of the order of eight hundred rounds a minute per barrel can be achieved. Actually, the weapon probably is going to be limited by the number of rounds of ammunition it can carry on the carriage , if it maintains this rate of fire for any length of time. Finally, we have the straight rocket class of weapon, LOKI, which has a large booster, 61 inches long and a small dart 34 inches long. Originally this weapon was designed to have some effectiveness at altitudes of about forty or fifty thousand feet. It really looks as if this weapon doesn't have the effectiveness required at high altitudes, but it is very promising in the lower altitude role.

Another weapon known as PORCUPINE is being developed by the Lincoln Laboratories in Lexington, Massachusetts. Its programme is essentially divided into the Radar and Ordnance equipment. The Radar is of rather interesting design; it has a broad beam at target pickup which narrows to a sharp pencil beam as the target approaches. The rocket that will be used is essentially an air-to-air rocket on which are mounted nineteen smaller rockets called quills in accordance with the name PORCUPINE. After several thousand feet of travel, the quills are released from the rocket motor and you have individual missiles travelling in the direction of the target.

Of course, finally, there is another weapon which cannot be overlooked. That is, of course, the old and still effective one of air interception. Mr. Sargeaunt mentioned earlier that in this country, guided weapons have now become the problem of the Air Force.

We feel that in addition to solving the problem of what is the best weapon, we are obligated to try and help with the problem of how many weapons we should have, and unless we can carry out evaluation of all parts of the problem simultaneously, we can never satisfactorily determine what the answer is to how many weapons we must have. So, we at ORO have been looking at all forms of defence.

To indicate the kind of solutions we've achieved so far, I'd ask you to refer to figure 1. The scales on this graph are logarithmic, both vertically and horizontally. Along the horizontal axis we have the altitude of the attack in feet. In this particular case it is a six hundred mile an hour aircraft having the vulnerability of a B-29 type aircraft, although the choice of vulnerability does not significantly change the results. The fuzing for the shell is what you would call Direct Action, and what we call P.D.; and on the vertical axis I've presented the cost in dollars per thousand yards of perimeter, that is, the perimeter on which the weapons are to be placed to achieve, in this case, a ninety per cent attrition. I should also add that in carrying out these calculations, we made the rather gross assumption that each of the aircraft was individually resolved by the radar, in other words, there was no problem of what happens to raiders in formations. Now, coming to the weapons themselves, we've put here the 90 and the 120 (mm), essentially our World War II weapons, and our 90 I think corresponds roughly to the 3.7" in this country and the 120 corresponds roughly to the 5.25". Actually, I believe the characteristics of the 3.7 are rather better than our 90 mm. You'll notice that as far as cost per thousand yards required to achieve this level of attrition, all the weapons tend to have their best characteristics, somewhere between two or three thousand feet and 10,000 feet. They fall off very rapidly at lower altitudes.

Now in the U.S. we also have a weapon known as SKYSWEEPER. It is a 75 millimetre weapon and it's rather better than we had in the last war, but still very poor at low altitudes. Incidentally, I should say how we set in low altitude limitations in the computations. We did it by making an assumption. We assumed that no shell ever arrives at an attacking aircraft when the line of sight from the gun to the aircraft is less than three degrees.

All the warning, fire control and track smoothing and so on have been achieved earlier than three degrees to allow a shot at the three degrees elevation and thereafter.

The next weapon is the 127/60. A tripartite agreement was reached that if a weapon of this general characteristic should be developed it would fire a 127/60 fin stabilized discarding sabot shell. Its characteristics are not good for low altitudes, it has a rate of fire in our calculations of one hundred and twenty rounds a minute, although I doubt if this can ever be achieved. LOKI, which is this straight rocket I talked about, has forty-six rounds in a launcher and it is believed that one can get all the rounds off in something of the order of three to three and a half seconds. I don't believe you can fire them in salvo because of the interference between each individual rocket, in other words, if you do, the ballistic dispersion becomes of the order of thirty or forty mils.

On figure 1 we notice the 70 millimetre gun-assisted rocket which is rather better than the rest at the lower altitudes, and the NIKE, which is an existing guided weapon in the U.S., which has been brought into being under crash programme conditions.

The point is, none of these weapons are very good at altitudes below a thousand feet. We feel that from the point of view of ordnance that is, of the actual instrument that fires off shells and missiles towards the aircraft, that there are really quite a number of possible solutions which would, in fact, destroy aircraft if there was time for tracking and warning, bringing people up to the weapons and so on. We feel that the basic limitation in low altitude defence is the problem of radar warning and radar tracking.

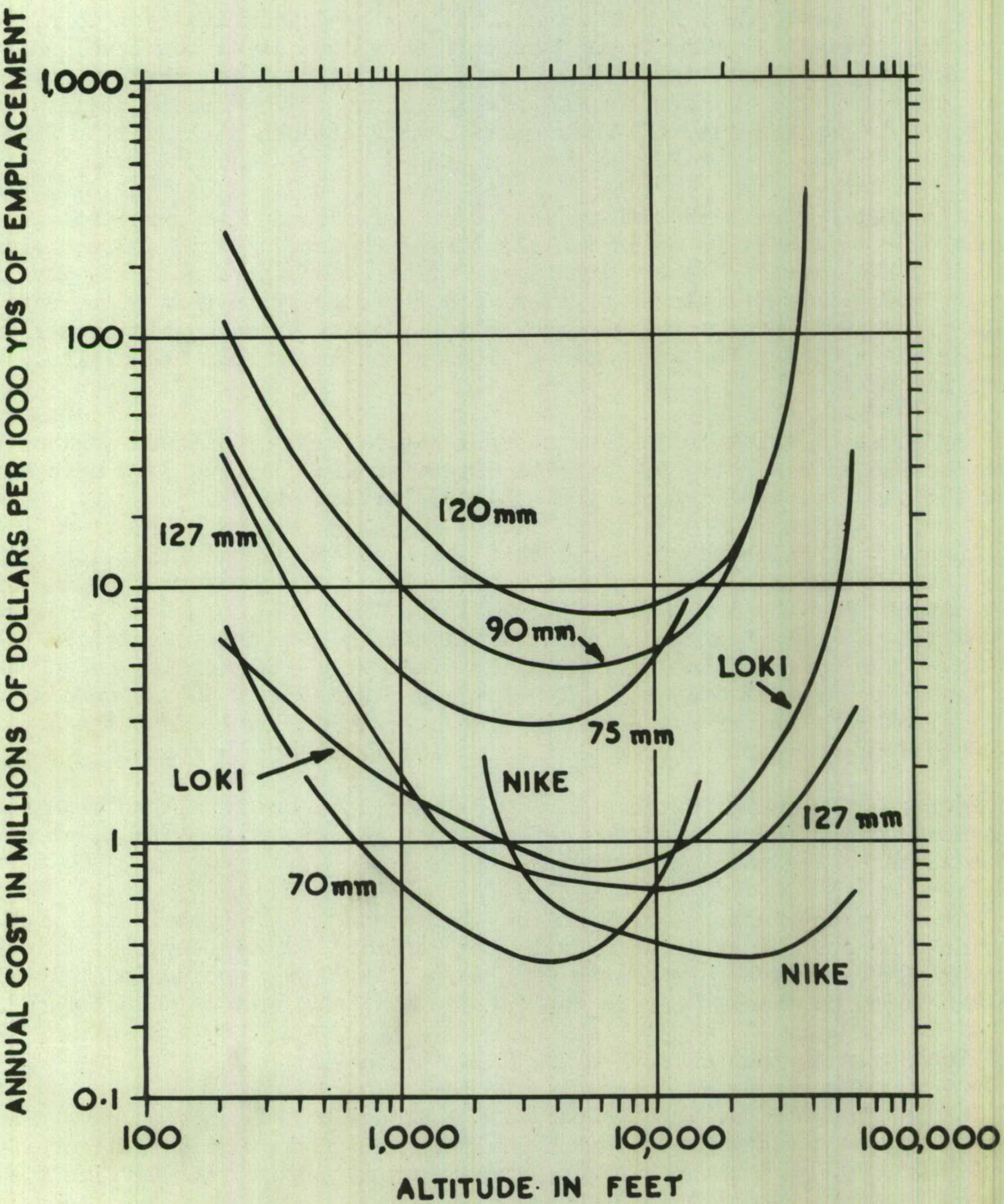
Now radars, of course, are limited by line of sight. I don't believe that any type of solution that tries to increase the power of the radars is going to add very much to the range. Several other alternatives have been attempted. One, of course, is to increase the height of the radar. I believe a solution in the U.K. is to put them in balloons and others to put them on high towers, and so on. Another possibility is to somehow or other to get the radar outside the defended area, having "picket" radars which will be satisfactory to carry out the acquisition process and also assist in the fire control. And, one might also go to rather unconventional types of radar. Perhaps one solution might be to have what is known as bi-static pulsed doppler radar, where the transmitter and receiver are separated widely, perhaps having an omni-directional transmitting radar in which only the receivers are at the weapon itself.

Certainly a few preliminary calculations which I made using nothing more than some of these handbooks of radar performance indicate there might be some possibility of being able to start tracking enemy aircraft something of the order of fifteen to seventeen miles away. The general system would be similar to that of a television set-up.

Nevertheless we do feel that the radar problem is the really serious one, not the basic ordnance of it. Finally, we might just mention what we are trying to do to speed up some of the computations that we're performing at ORO in this role. I am sure many of you, or at least some of you, have been exposed to doing some of these anti-aircraft calculations, and they become very tedious after a while, particularly if you have to change the co-ordinates frequently, change the direction of attack, and so on. We at ORO have developed a scheme which at least for some cases, can be put onto one of these high speed electronic computers, which save us a great deal of time. It still takes several months, but we can perform calculations more easily with wide variations of the parameters pertaining to air defence. We may find, actually having done a number of these calculations on the machine, that we'll be able to develop empirical rules which will permit rapid hand calculations later.

COST-EFFECTIVENESS.

ATTRITION—90% ; RAID—9 A/C (B-29 VULNERABILITY) ;
SPEED—600 m.p.h. ; FUZE—PD (EXCEPT NIKE) ;
NO MANEUVER



At the conclusion of the paper by Mr. Henry, general discussion was invited.

Mr. Ross. "I think that it is important that we should be quite clear in our own minds what we mean when we speak about "the low level gap". We find that we are able to achieve a reasonably high attrition rate for reasonable expenditure against attacks from high level, but for a comparable expenditure against low level attack we can achieve only a much lower rate of attrition. We say, therefore that there is a low level gap. But until we have made a serious study of the facilities needed to carry out a low level attack and compare them with those needed for high level attack, we cannot say how serious the low level threat is. There is a school of thought which suggests that although a low level attack is technically possible, it is expensive since more highly skilled pilots are needed, and there may be considerable expense involved in the use of navigational aids (and these may, in any case, provide early warning to the defence). Furthermore, it may be difficult, even then, for the attacking aircraft to find their target if they come in at low level and they may, in fact, be forced to come in at a high altitude, find their target, and then attack it from a lower level. If the aircraft do come in at low level for the whole or the majority of their sortie, many attacks will fail to find their target.

All this suggests that there is a case for assuming that the low level threat is not so serious as is the high level threat. It is quite obvious that if a high level defence alone is provided, then there is a low level threat, but this surely is no argument for the suggestion that it is not worthwhile providing a high level defence only. Unless a reasonable high level defence is provided, the enemy is at liberty to attack from the altitude which suits him best.

In short, I think we must be careful not to assume, without serious study, that because we can get a 90% attrition rate at high altitude, we necessarily need the same level of defence against low altitude attack."

Dr. Rumbaugh. "Although we agree that the navigational difficulties of low level attack may be serious we must nevertheless face the fact that the enemy will attack from the level most favourable to him. We should not, however, forget the progress being made in navigational and bombing techniques. Our own Navy, for example, in developing its minelaying capabilities has emphasised the low level aspects and, as early as 1946, altitudes of 500 ft were under consideration. In our Air Force too, we have under development the so-called LAABS system, in which the emphasis is on low level toss bombing."

Mr. Moore. "The cost to the enemy of delivering a low level attach has to be balanced against the cost of the defence against it. I feel that, at present, the advantage lies with the attacker.

On the point made by Mr. Ross that the use of navigational aids may provide a measure of early warning to the defence, I would say that this warning solves only a part of the problem. The planes coming in at low level still have to be tracked before the defence can take action against them".

The Chairman then called on Mr. Cole to speak.

Mr. Cole. "Gentlemen, in our Operational Research in Canada we have been giving most of our attention to the analysis of defence against attacks from about 5,000 ft. We have, however, given some thought to the difficulties of defence against low altitude attacks.

As has already been mentioned, one fundamental difficulty of low level defence is the shortness of the time available to deploy the defence. We believe that as defence against high and medium level attack becomes more effective, the lower altitudes become more important. The enemy will, presumably, wish to achieve surprise in the delivery of weapons of mass destruction, and low level attack is one method of obtaining this surprise. The problem of navigation and target identification has already been mentioned, but I believe that the new types of navigational aids (e.g. inertia systems) will enable an aircraft to make a landfall quite close to some identification

point from an altitude of 500 or 1000 ft. From then on, it should be quite easy for a well-trained crew, in daytime, to proceed overland to the target, using contact navigation.

Although low altitude raids are easier in daylight conditions when visual aids to navigation are possible, the same conditions make the problem of defence easier also, because ground observation troops can be employed for tracking the aircraft over the land and the enemy can be engaged under visual conditions.

The low altitude attack at night is very difficult, I understand, because of the difficulties of navigation and of target identification, but in certain cases very important vulnerable areas lie along rivers which provide very fine natural track lines. I am thinking, for example, of the St. Lawrence leading to Montreal and the Niagara Peninsula in my country, and the Thames leading in to London.

I would like then, briefly to mention low level defence methods and their application in Canada. A suggested daytime defence depends primarily on a dense carpet of observer posts over land, with extra low looking radar on the coast. The extra low looking radars have never been really successful because of the sea clutter, and in any case it would not be possible for a thinly populated country like Canada to use the Observer Corps on any extensive scale. In daytime, fighter aircraft armed with guns appear to provide quite a reasonable answer, judging from the results of exercises which have been carried out, but the main trouble will be that, because of the short warning time, it will be possible to get only a few fighter aircraft into the air in time.

Light AA guns, particularly those with a very high rate of fire, appear to offer a fairly effective defence, but the major trouble is that each gun can look after only a very small front, and this would imply an extremely large number of guns if a large country or a large number of vulnerable areas was to be defended.

I sum it up by saying that the present low level defence is about the best that can be done with existing types of radar and weapons, but even after all possible time consuming elements in the defence have been reduced, it still cannot be considered satisfactory, and I do not believe that it could be used in Canada.

I should like now to consider briefly the future trends of low level defence in relation to Canada. In areas of Canada where our own aerial activity is on a very small scale, it should be possible to use a system of closely spaced Doppler type radio posts. Any aircraft penetrating this screen gives an alarm. This helps considerably in reducing the state of readiness at which aircraft and their crews and ground radar personnel must be held. The system will work, of course, only when the flying of friendly aircraft over the area is on a small scale for otherwise the number of false alarms will defeat the purpose of the system.

A possible solution of the early warning and radar tracking problem for the large and thinly populated areas of Canada would be the use of balloon borne radar at an altitude of about 500 ft. with stations placed about 100 miles apart. This system should be capable of tracking aircraft down to about 500 ft. To avoid the logistic problems of supply, long range weapons would be needed with about fifty miles range. Our preferred solution is a long range guided missile with command guidance and some form - CW radar or infra-red - of terminal homing. If such equipment is technically impossible, then we should have to fall back on defence by fighter aircraft carrying air-to-air guided missiles and with special low-looking radar for the AI. At night, the problems of flying and manoeuvering fighter aircraft at high speeds and low altitudes will be very difficult."

The Chairman invited questions on Mr. Cole's paper.

Dr. Rumbaugh. Have you tried to make any study of the relative cost of missiles versus guidance systems here. You have spoken of a range of 50 miles for the missile, but have you made any attempt to weigh the cost of the guidance system against the range of the missile it is guiding."

Mr. Cole. "That is one of the subjects on our programme, but so far we have not been able to do any work on it. I think some studies on the point have been made in the U.K., and the answer, I believe, is that a weapon of about 50 miles range gives the best compromise. Points to be considered in arriving at this compromise are the necessity for being able to defend against large raids, and the desirability of avoiding waste of missiles by not having too many directed to the same target in the air at once."

Dr. Page. "Could we be reminded how far the radar fence is in front of the target?"

Mr. Cole. "The radar fence is some distance ahead of the tracking radar, and our analysis has shown that in the medium and high level case the distance should be great enough to give about 20 minutes warning. Of those 20 minutes we have assumed that about 10 minutes are teken up in checking that the warning is not a false alarm and in deciding what forces are to be alerted."

The Chairman then called on Mr. Barham to speak.

Mr. Barham: "Gentlemen: it seems to me that we all agree fairly well on the nature of the problem. I should like to touch on a few points which I feel are important. Some of them have been mentioned already and in that case I shall speak about them as briefly as possible.

The first point, obviously, is to decide how serious the low level threat really is. This has been discussed already, and it is obvious that this threat will increase as defence at the higher altitudes becomes more effective. Another point that might be made is that the problem of defending a country like the U.S. or the U.K. is different from the problem of giving protection to an army in the field. In considering the threat, I think we should separate the two aspects quite distinctly.

One of the main points about low level defence is, as has already been mentioned, the radar problem. At the present moment our main low altitude defences are light AA guns. So far as point defence is concerned, they are reasonably efficient, and with the projected new fire control system they may be made much more efficient. I am thinking in particular of the RED INDIAN fire control system which is under development in this country and which, in its first stage, will have radar range and regenerative tracking. A later version may have full radar tracking also. But even these new systems will not be of much use unless there is sufficient warning given of the approach of an aircraft. This applies particularly, of course, with modern aircraft with their high speeds. One needs more time than ever to do the necessary acquisition and tracking.

Dr. Rumbaugh has raised the question of optimum weapon range. This question was considered by the GREEN WATER Working Party in this country, which made a study of guided weapons in defence. One of the conclusions drawn from the economic data used in this study was that, if guided weapons are used for the main defence, then it is economically preferable to have one weapon effective over the whole altitude range rather than to use an integrated system with two separate weapons.

For the low altitude defence, two schemes were considered. The first was a guided weapon of fairly short range, twenty or thirty thousand yards, which would home all the way. This obviously needs more radar coverage than exists at the moment. The ranges were short enough for the weapon to be controlled entirely from the launching site; in other words, the system would be self-contained. The second system considered was something like the American BOMARC scheme, the weapon part of which is of much longer range and has mid-course guidance and terminal homing. The range of the weapons considered was up to something of the order of two hundred miles. From the figures that have already been quoted it is quite obvious that in order to make the system work against low altitude targets it is necessary to have a network of ground radars all feeding into a central control station for each missile site. The GREEN WATER Working Party tried to compare the economics of the two systems, and it appeared that there was considerable advantage in extending the range beyond the 20 - 30 thousand yards of the short range homing weapon. A range of the order of one hundred thousand yards appeared to be the best from an economic point of view.

Another factor which has to be considered, of course, is the technical difficulty of the proposed system. In the long range system, there is the technical difficulty of providing the network of radar cover and there are the associated problems of feeding information into the central control station. One would also need large and complicated computing equipment. But assuming that these difficulties could be overcome, the optimum range was about a hundred thousand yards.

Another thing which must be considered is the part that fighters will play. The question of the use of fighters at low altitudes is a difficult one. There is first of all, the question of giving adequate early warning and unless one is to have standing patrols it seems that fighters will need longer warning than guided weapons or guns. There is, too, the question of just how effective fighters will be at low altitudes. Against daylight attacks they may be reasonably effective, but for night attack radar problems crop up again.

Although I am not a radar expert, I should like to say a few words about the radar problem. I attended a conference in U.S. recently on the low altitude target problem; this lasted three days, and nearly all that time was taken up discussing radar problems. The generally favoured scheme for tracking low altitude targets was some sort of C.W. radar. The Americans think in terms of pulse Doppler systems in which both range and velocity information is obtained. There is still the problem of getting adequate range with the radar, and the scheme which has received most support in this country is that of raising the radar, or at any rate the aerial, on a balloon. This was looked into a year ago and it did seem a promising scheme. It appeared possible to get up to altitudes of about 5000 ft. and obtain a range of about seventy miles on targets at about fifty feet or so. This, I think, shows promise from the point of view of getting adequate warning on low flying targets.

Another major difficulty is that of identification. This is a problem which will always be with us unless our air forces agree that they do not mind having their own planes shot at occasionally. If, in spite of all improvements, we are still very limited on radar range, there will just not be time to identify aircraft which have been detected and the only solution will be for friendly aircraft to keep out of the way".

At the conclusion of Mr. Barham's talk, general discussion and questions were invited.

Dr. Page: "I am puzzled why the solution adopted by Britain in the last war, namely barrage ballons, has been ignored in this discussion."

Mr. Geeson: "When we were gathering information in the U.K. for a study of possible low level solutions we asked many people about balloons. The general feeling was that with ordinary steel wires, it was not possible to get sufficient wire into the air to make the solution worthwhile. A possible alternative lies in the use of cables of various plastic materials. Under the particular conditions, it was thought that some of these plastics might have better characteristics than steel wire for damaging high speed aircraft. Very little effort, however, is being put into this work."

Mr. Ross: "I think what we have to go for on this is some sort of long range defence system. There are, however, two difficulties in this. One is the problem of warning with the limitations of optical range, though this can be overcome at some expense. The second problem is the limitations imposed by ground clutter which is present whether we use fighters or guided weapons for defence. There have been suggestions that C.W. radar can aid in this problem. Perhaps I am not up to date in my knowledge of C.W. radar, but the only serious contributions to the subject that I have seen have been discussions, on the basis of information theory, trying to show that C.W. radar can give all the answers that a pulse radar can. I have never seen any serious studies on the possible application of C.W. radar to specific problems, for example the problem of designing a small economic homing system in a missile or to its use in A.I. It is quite clear that you can get the information you want from a C.W. radar, but what we want to know is whether the radar is more or less complicated than pulse radar, whether the information is provided in a more or less convenient form, and how the economics of the two systems compare."

Mr. Hill: "I should like to make one comment on the application of C.W. to guided weapons. In this country, TRE has been doing experimental work and this has now reached the stage where a proposal has been made for a complete C.W. active homing weapon. The proposal does reinforce Mr. Ross's remarks. The solution they envisage would lead to a very complicated radar. They do not see, at the moment, any solution of the problem of common T and R working, which means that they require two quite large dishes, and this presents considerable technical problems. We have not yet evaluated the system at RAE but it obviously has to be done. We have, in fact, to find out whether the solution is not so expensive and so difficult that certain conclusions of GREEN WATER are still valid."

Mr. Kaye: "I should like, for a moment, to consider the defence of the field army. I think this is likely to be a little behind the defence of civilian areas. There are two types of target: the more or less stationary installations and roads, and mobile small targets such as vehicles. We have not done a great deal of work on the problem, but we have done a little on the question of vehicle movement along roads subject to enemy air attack.

First of all I should like to say something on the subject of attrition, because I think that the army and civil points of view may be a little different, although the problems are basically the same. From the point of view of defence of a vehicle or something small of that kind, it is really only a question of defending when an attack is being made on that particular target; there is no question of a large perimeter and a large number of guns or instruments collected together. What is needed is something which can be moved around very quickly and you can defend yourself with just one small item of equipment, a small gun or something of that kind. The main thing is more a question of discouragement of the attacker, of putting him off his aim rather than of attempting to shoot him down. In fact, if you do shoot him down he is probably going to hit you anyway. So the main object must really be to put up sufficient fire to discourage too many attacks on a vehicle or other vulnerable point.

The work which we have done is concerned with the movement of vehicles in convoy along a road and with determining the defence that is given by some small weapon such as a 50 calibre machine gun. Problems of early warning here, although important, are less important, I think, than elsewhere because normally there will be a general warning of aircraft in the area and personnel will be more or less alerted and standing by. Engagement will be at extremely short ranges, less than a thousand yards, so that provided crew are standing by their guns there will be a reasonable chance of manoeuvering to get some shots in. So the questions we seek to answer are: where should the guns be in a convoy so that vehicles can support each other, how many should be together, how long should a convoy be, and so on.

The conclusion we arrived at is that if you have a convoy you desire to protect by guns mounted on the vehicles, the best chances of success against all possible directions of attack are given with a long convoy with close spacing between vehicles. But on other grounds, we find that a long convoy is extremely vulnerable in the daytime if the enemy has air superiority. It is necessary, therefore, to compromise by using a short convoy, and it is then necessary to find the best compromise solution."

The meeting continued with a paper by Mr. Geeson.

Mr. Geeson: "I should like to take a little time in amplifying and adding detail to points made by previous speakers. The first point is the dividing line, in altitude, between low level and high level attack. Two thousand feet has been suggested, and I would agree that this is a satisfactory dividing line. If an aircraft is flying at two thousand feet then, generally speaking, our radar defences are not in difficulty and we can detect the aircraft and begin tracking and we have sufficient time to carry out all the necessary operations in defence. Anything above two thousand feet, therefore, does not present us with too difficult a problem, and this is so for aircraft with speeds of up to 600 knots, or even more. I think it is important to get this question of height correct, because there is a great tendency for people

who are considering short range weapon defences to strive for effectiveness at ever increasing altitudes and whilst it may be nice to have an automatic AA gun which engages targets at ten thousand feet or more it confuses the issue in a discussion of this kind if some of us are thinking of heights of two thousand feet, while others are talking of about ten thousand feet.

Next, I should like to talk about the threat itself. Previous speakers have, quite rightly, asked whether we are not making too much of the threat. I think it is true that there is a threat. As far as the field army is concerned, we can get some evidence from Russian tactics during the last war. They certainly appeared to like to attack at low level, and all the information we have from intelligence sources suggests that they have a tremendous organisation directed to the making of low level attacks in the field. Quite a lot of the targets in the field army are, of course, particularly susceptible to low level attack.

Points have already been made concerning the identification of targets on the ground. This may not be too difficult. The technique of marking targets with artillery smoke shells is well known, and by night targets can be marked by directing searchlight beams along the tracks the aircraft are to fly.

If we turn our attention to base areas and home defences we find that our coastal areas at least are very susceptible to low level attack. Our present early warning system in the U.K. gives coverage of the order of 30 or 40 miles on low flying aircraft. With an aircraft speed of, say, 600 knots, this gives about 200 seconds warning. This is not adequate for getting fighters into the air and on to the raiders. Even gun defences may be hard pressed. As far as inland targets are concerned, there may be some further advantage to the enemy in attacking at low altitude. Even if he doesn't make his main attack at that level, it offers him opportunities for spoofing. There was, for instance, an exercise carried out in America recently in which a high level bombing raid came in and was detected and met by the defending fighters. At the same time a number of aircraft came in at low level. They were just not noticed. There is a tendency for the operators of the reporting system to concentrate on the good radar target at high level and thereby allow the low level attack to remain unnoticed. On the whole, then, I would say that a low level threat exists for this country or for any base area. What we really do not know, however, is the likely intensity of the low level attack.

Now a word about the atomic bomb. We have been used to the idea that atomic bombs have, for various reasons, to be dropped from high altitudes. If, however, it proves profitable to drop them from low altitudes, there seems to be no reason why a suitable technique should not be devised.

Let us turn now to the objects of the defence. I wonder whether we are not over-emphasising the question of achieving actual kills. For example, a warship is generally concerned purely and simply with survival. If it can beat off the attacking aircraft without being sunk, then it is quite happy to do so. It may be nice to shoot down a few of the enemy - this may, in time, deter the enemy from attacking. But the main object, certainly of a thing like a warship, is to self-preservation, and the same may be true of our small VPs in this country or in the field.

The question of balloons was raised earlier. My impression is that they have been rejected as a means of defence in this country, but I believe the evidence of which this rejection was made is questionable. We know that they did not destroy many aircraft in the last war, but they did, in fact, achieve the purpose for which they were designed, that is they forced the attacking aircraft to fly high. So there may well be some advantage in having a balloon defence which will force aircraft up to, say, the 2000 ft. level or higher where they can be attacked more effectively.

What means of defence have we available? There is first to be considered the question of warning. A comparison has been made between early warning sets carried in aircraft and in balloons, and it was decided that the balloon-borne set was a better proposition that the aircraft-borne version. There are several reasons for this. Firstly, aircraft are more expensive to maintain in the sky. They cannot be flown continuously whereas a balloon can be

flown more or less continuously until it is shot down. Again, the balloon can carry a much more powerful radar. The power supplies can, if necessary, be piped up the cable to the set, whereas an aircraft has to carry its own generators. Then there is the question of correlation of the data produced by the various parts of the radar system. With the aircraft-borne set it is necessary actually to track the radar aircraft, plot it at a ground station, and then correlate the data produced by the aircraft with the position of the aircraft itself. With the balloon-borne set, generally speaking, the position of the balloon is known to within quite small limits, and the information can be used direct. As far as the question of orientation is concerned, it is possible to use some standing break on the ground to give a point of reference from which the orientation can be deduced.

As for local warning, a certain amount of effort in this country is going into the production of a picquet radar - the sort of set that will tell air sentries that there is something moving in the sky nearby and that they should be looking out for it.

A question that I want particularly to speak about is that of identification. This question, I think, has not so far received sufficient attention in this country. The procedure with a low-level aircraft in the U.K. is that immediately upon detection the radar plotted position only goes forward very quickly through the control chain with the code-word 'Rats'. This means, purely and simply, an unidentified low level aircraft. An unfortunate aspect of the various air exercises which go on in this country is that all these 'Rats' are obviously Fighter or Bomber Command planes - they are certainly friendly aircraft. What a 'Rat' plot means really, as far as Fighter Command is concerned, is that fighters will be scrambled because of the risk that it may turn out to be a hostile aircraft. But when the defending fighter meets this low level aircraft it is the pilot's job to identify the plane before he actually opens fire on it. Now the same sort of thing should apply to the gun defences but there is a great tendency, I am afraid, to regard a 'Rat' as a hostile target and to open fire immediately. A possible solution of the problem is that of controlling the position of our own aircraft so that they do not fly over our gun defences. This is quite possible with an aircraft that is fully operational and has its navigational aids and radio working, but the trouble will always be the 'lame duck'. This aircraft has probably already been shot up and the pilot may well not know his position accurately. This is just the aircraft which does not want to be shot at by our own troops.

Then there is the particular problem of airfield defence. Airfields are bound to have many aircraft coming in low down - their own planes coming in to land - which must not be shot at. At the same time, the very organisation of an airfield system should allow for some identification. Generally speaking, each aircraft coming in calls up the air field and asks for landing orders, and it should be possible to pass this information to the gunners.

Nevertheless, the whole question of identification is particularly difficult so far as low level defence is concerned because of the very short time available.

A final point, to which attention was drawn during one of our exercises, is the question of fire distribution. An attacking enemy force, in order to reduce the amount of fire it is going to get, is likely to come in in groups of 2, 3, 4 or 5 aircraft at a time. The system of fire distribution we have at the moment generally results in all the fire being directed at the very first plane that comes along, or possibly the first two, and there seems to be a need for distributing the fire over the whole attack so that the rearward aircraft or those coming in on the side, do get a measure of the fire than can be provided by the gunners."

At the conclusion of Mr. Geeson's paper, the meeting was opened for general discussion, and the chairman first called on Dr. Paxson to speak.

Dr. Paxson: "It does seem to me that two points have not so far been stressed; one in fact has not been mentioned at all. I think it is worth pointing out that defence against low flying aircraft is simply part of the overall defence problem, and we can go very sadly astray if we try to think of this as a linear problem in the sense that we get the best defence for a point and then simply multiply this to get the best defence for a system. These problems are definitely non-linear. They have to be thought of as defence of a whole country, or, in the case of ground warfare, defence of the whole battle area.

If only because of the fact that targets have different relative values, the question always arises as to how you are going to distribute your defence effort with respect of these targets. Are you to distribute the defence so that a few of them are defended heavily and the rest very lightly, or are you not? There is the question of the form of the enemy's attack: is he going to try to saturate you with mass raids or will he try to keep you continuously exercised? I am posing this only as a problem, with the suggestion that the answer is not found by a simple linearisation method.

The other thing that impresses me is that we still seem to be at the point where we are thinking of future development which, somehow or other, never really seems to come along. I would argue that we have a higher responsibility, which is to investigate the question of a defence posture which is valid from the present on. I do not think I am wrong in assuming that the original definition of Operations Research involves current operations, and this is self-criticism as well as criticism of the group when I say I think we sometimes forget the present in favour of making for future developments.

If you accept the problem as a systems problem in which you are trying to balance out the economics of an overall system in deciding how much money should be spent on an early warning defence, on the tracking network, on the point defence missiles, on the aircraft alerting system and the aircraft direction system, then I think the techniques of solving the problem, given the facts, are well established. They are the usual methods of marginal equilibrium and, in fact, several papers written some years ago in U.K. worked this problem out for the air defence case, and showed how the money should be distributed among the components of the system to maximum the effect desired. In this particular case, it was the probability of successful interception and kill which was to be a maximum. In our case, it would be either the total number of kills about a base line or, as Geeson has suggested, it might be the total number of aircraft diverted or prevented from reaching their target. The technical methods for the systems problem need give us, I think, no real trouble.

The conceptional problem, that is how you distribute your defence with respect to calendar time is, however, still there. I would like to mention two specific points in this direction, two things which could be done almost immediately as opposed to those things which seem always to be four or five years away on the time scale.

One, and this is for point defence, is the notion of very simple automatic barrage rockets of almost any type you choose, e.g. any existing type arranged in a ring and preceded by an outer concentric ring of a simple type of VT fuze or alternatively, a system of grenades, moored by cables and erected by rockets or mortars, using similar fuzing (called FAST FAKIN). I would like to quote some numbers on a calculation for this case to indicate the potential value of simple unconventional weapons.

I am speaking of an annual defence budget of five million dollars for each weapon system. I am violating my principles and being linear at this stage in speaking about one point being defended, and everything I say refers to medium piston-engined bombers like the TU 4 or the B 29. For this case, that is for a fixed annual defence budget of five million dollars defending a point against medium piston-engined bombers, our calculations have shown that the kill potential, that is the number of aircraft that could be killed if the defences were saturated goes as follows. For the 40 mm mount it is 0.3: for

an advanced type of 30 mm gun not actively considered it can be unity; for the T 212 rocket gun 0.7; for the auto-barrage rocket up to 1.7 and for FAST FAKIN about 2.5. These figures are for a daylight attack at 200 ft. without evasive action.

Against a night attack at 1500 ft. we have the following figures: LOKI a kill potential of 0.6; the 75 mm SKYSWEEPER a kill potential of 1; the T 212 rocket gun will radar fire control 2.1; the automatic barrage rocket 0.4; and FAST FAKIN 2.5.

A question I would ask is has this type of simplified system been investigated by any of the people represented here. It seems to have considerable promise.

Correspondingly, again along the lines of improving our immediate posture, but not necessarily at the expense of future posture, various proposals have been made for handling the very significant tracking problem of low flying aircraft. One of the best that I have heard of involves the notion of using normal airfield surveillance radars which are very rugged and reliable and are mounted on 60 foot towers with automatic transmission of the radar picture to a G.C.I. centre where the picture is automatically combined with data from other radars. This seems to me to be a systems engineering problem of a sort that could probably be turned over to a telephone company.

Another possibility is to improve the ground observer system. This improvement would probably take the form of sending coded positions at the aircraft observed directly to a telephone exchange. Unfortunately, this would involve the development of storage device which would, in turn, feed the stored information at the optimum rate into the G.C.I. centre and this information could immediately be shown on a P.P.I. display. These last two schemes have been investigated in detail and seem to offer considerable promise.

In conclusion, let me repeat my main thesis that we should not be hypnotised by the future and we should think in terms of improving the immediate position".

Mr. Sargeaunt: "Thank you. I would like to hear more on this question of what can be done now and therefore I will ask Col. Macklen to speak."

Col. Macklen: "In BAOR we are, of course, faced with some stark realities. By our terms of reference we have to relate our answers to the equipment and to the state of training of the people we have. This means, in fact, that we have an inadequate number of guns to spread over a large number of targets, and that we have troops generally of a low standard of training.

First of all I should like to outline our facilities. We have only the light anti-aircraft defence, ordinary machine guns on anti-aircraft mountings and 40 mm Bofors, single mounting, either towed or self-propelled, and the number of these guns is extremely small. The state of training of the troops is reasonable for a national service army, but it is, of course, considerably below that which existed at the end of the last war when the soldiers had operational experience.

The targets to be defended for an army in the field are very different from those in the home base. We are interested more in pin-point targets than in large installations, and our guns are therefore distributed in a different way. In fact, for small pin-point targets in the forward area, there is no 40 mm gun defence at all. The defence here will be concealment alone. Concealment is a defence against low flying aircraft. We have so concealed headquarters of Army Group size by camouflage as to make it almost impossible to detect them either by photographic or tactical reconnaissance. This is not so difficult as it sounds when you remember that on only about 30% of days in northern Europe is it possible to carry out reliable air photography and on only about 50% of days can you get reliable tactical reconnaissance. Headquarters have been trained, and are continuously being trained, in moving quickly once they have been discovered.

Another method of defence we have looked into recently, which is applicable to defiles in the supply line and in the forward areas, such as road bridges, and important centres, is that offered by smoke cover. We did a quick economic survey and we find that to produce continuous smoke cover over a target the size of a fairly large road bridge costs about the same as it would to defend it by a regiment of light AA guns, assuming, that is, about ten engagements a day. The gun defences can be saturated, but the smoke defence cannot be saturated.

We carried out a trial recently on the effect of smoke on low flying aircraft, and although the results are not yet fully analysed, the indications are that under the conditions of the experiment (very hot day with practically no wind) we could, with a fairly small expenditure of smoke, have made low flying attacks and dive attacks tractically impossible. We could also have made a medium bomber attack from 10,000 feet practically impossible except from a very few carefully chosen directions of approach. On the other hand, of course, smoke offers no protection against bombing with radar aids.

There is a further point about the defence of the field army which I should like to make. There is no radar attached to our light AA so problems of tracking, and also to a large extent, of early warning, do not exist. We will be extremely lucky in the present position if anything but an aerodrome defended by light AA gets any early warning at all. There will, of course, be the normal drill of putting air sentries out in a ring around the GDA but a few calculations show that you have to use a very large number of sentries in order to achieve a 50% success on sighting aircraft in time to get the guns into action.

The difficulties of making low level attacks have already been mentioned. We consider that these difficulties are greater than would appear at first sight. The 2nd Tactical Air Force have been studying the problem. It appears to be extremely difficult to locate the target unless the aircraft come in on a high approach and then finally make their low level attack. In actual war conditions, it is not always possible for the pilots to know where the target is, since there is a delay of an hour or so between the calling for and the delivery of the air-strike, and in an hour the situation may well have changed considerably."

Mr. Cole: "We have given more attention to the logistical aspects of the problem than to the tactical aspects. We are in exactly the same position as the British Army of the Rhine. We have limited numbers of weapons and limited manpower, and we have the certainty that low level attacks will be made and that they will have very considerably chances of success.

Since the question has been raised, I should like to point out that, in the static conditions existing before the balloon goes up, the enemy should be in a position, during the first and vital days, to be able to locate his targets quite easily without going up to high altitudes to look for them. In a number of cases in our own zone, and this, I believe, is true in the north also, the autobahns and railroad lines lead directly to installations and there is every inducement for the attack to be made at low level. As we see it, there should be relatively little requirement for the aircraft to go up to high levels to search for their targets. We have therefore assumed that low level attacks will get through and with the weapons we have available at present there is not much that can be done about it.

Since we cannot get at the planes, we have tried to see what can be done about the targets. Even under the present limitations of manpower and money, there are possibilities. We have, in the first instance, set up what we may call the target entity, or target unit, and we have tried to see how you can arrange these target units so that one weapon dropped from a plane, or one pass, will get only one target unit. This has been our first approach, and we have worked out some figures estimating the dispersion we need against three types of Russian planes, and at various strengths of attack.

The second line we have taken is to determine how best to repair damage to the transport system. We assume that damage will be inflicted: that under the present system we cannot prevent it. We have looked at our system of road and rail communications, and tried to estimate first where damage will occur and second, what steps of organisation, mechanical implementation and so forth, must be taken if the damage is to be repaired in the shortest time with the number of men we expect to have for this work. Obviously, in this study, we have had to examine our whole logistical system to see what parts of it are most vulnerable. It has been a long study, and we are coming to the conclusion that we have to divide our repair effort equally through the whole system."

Mr. Sargeaunt: "We have already spoken on the magnitude of the threat of low level attack. Col. Macklen, perhaps you have some information from our Air Force in Germany on the practical aspects of such attacks."

Col. Macklen: "There is an element of low level attack in all exercises but it is always restricted to specially trained pilots. The view, I think, of the Air Force (though I can hardly commit them) is that their Regular pilots are capable of carrying out attacks from really low levels, 50 feet or even 20 feet, on targets about which they have really good information. But they believe that if there is any opposition around the target then the level of attack will tend to increase, even with experienced pilots, up to about 500 feet, and they are certain that when they get replacement pilots the level of attack will be even greater."

Maj. King: "I would like to say a few words about the air tactics used on exercise Coronet. The 'enemy' fighters took off from bases in the American zone and in France and they flew at high altitudes for a very short time only. They came into the defence radar cover long enough to give only one or two paints on the radar tube. This meant that there was no possibility of the defence identifying the aircraft or even establishing the track. The opinion was that the Russian Tactical Air Force would probably fly in this way and it seemed to me that the problem is largely a question of local warning, using air sentries and so on. What degree of effort can you afford to put into O.P. parties, communication channels and light AA control centres. The more you extend your range of warning, the more O.Ps. are needed and the more complex the control centre needed. But it looks as though something on these lines is the only way we will get any defence at all against certain pin-point targets.

At Byfleet we have at times wondered if jet-engined aircraft could not be attacked, by some unconventional means, through their air intakes. Is it possible to get something sucked into the air intake which will destroy the engine? I should also like to endorse very strongly the suggestions made earlier about barrage balloons. With the highly stressed wings of modern aircraft barrage balloons may have a new part to play."

Mr. Sargeaunt: "Now I think we might look further ahead. I should like to hear something on the guided weapon side."

Mr. Hill: "I don't think we can go very far ahead in the assessment of the low level problem yet. We have tried to make an estimate of the limitations of a possible first generation of surface to air G.W. at low level. The overall system, consisting of early warning, tactical control, lamp set, and missile head, seems to give a lower limit of effectiveness of about 6000 ft. If we extend the same system to give greater range this lower limit is going to increase, and so, although I spoke earlier a word of caution about a C.W. system, it is, at present the only system we can see which shows any great promise. The difficulty is that at the moment a C.W. system calls for two aerial dishes and this leads to a more complicated type of missile.

I am not trying to suggest that the conclusions of the GREEN WATER party were wrong. They postulated a missile which seemed a fairly logical development of the first generation of missiles; it may turn out that this missile is so much more complicated that the line of argument used is wrong. Although the conclusion may be right, it really wants thinking out again. To get a long range missile which is effective both at high and at low levels is going to be a very difficult technical problem, and though it may ultimately be the correct solution it may not be possible in the second generation of missiles."

Mr. Henry: "I would like to make a few remarks in connection with the guided weapon low altitude defence. I feel that one of the things which may very well decrease the possible range of guided weapons is the old problem of reliability. In general, as you increase the range of a guided weapon you increase its cost. This means that for a given defence complex, whether it be the defence of a field army or of a home base, and for a given defence budget, the longer the range of the missile, the fewer will be available. Now we must consider the reliability of the missile. Our experience so far with our NIKE missile is that, although pre-firing tests show that everything is in order, yet only 50-60% of missiles fired behave as they should. In addition to this, we must remember the time taken to get the missile ready for firing, during which the missile is, of course, completely inoperable. I suspect that, when it is first installed, the operability factor for the NIKE system will not be above 10%. Larger missiles (and fewer of them) would suffer even more from this operability factor than the shorter range NIKE."

Mr. Gould: "I believe that at the moment we are thinking too far into the future. We would all like to see an ideal weapon which could be used both in defence of the field army and the home base and be used at all heights. As far as we at AORG are concerned, a certain amount of the U.K. work has been taken out of our hands by the decision that the RAF are to be responsible for G.W.

Consequently, we are left with consideration of the defence of the field force and possibly some VPs in this country which may be left under the control of the Army. It seems to me, therefore, that it is still possible to think not only in terms of one ideal weapon but of two weapons, one of which may be G.W. but the other could be a conventional gun, or an unconventional gun or something else, particularly as in the field of guns, conventional and unconventional, it seems to me that there is some hope for achieving economic lethality. Recently, with the introduction of RED INDIAN we have a gun with a fire control system which incorporates in itself its own tracking and fire control arrangements and also gives some degree of early warning. The great advantage of a gun is that, although it is admittedly only a local defence, it does require only local radar warning. A gun does not require warning of 30, 40 or 50 miles. If we think in terms of targets which can be defended by guns, such as field army units or VPs in this country, the question is whether a gun defence is economically as good as the ideal we are looking for. Recent figures on the lethality of the RED INDIAN system are most heartening in this respect. It seems that for the defence of a single VP in the field, or even in this country (such as a coastal port or an airfield) the lethality of quite a limited number of guns is very high, and in fact it is possible to extend a system of 40 mm RED INDIAN controlled guns to the defence of a perimeter system, even such as London. The first rather elementary figures which have been produced show that, economically, it is a proposition to be considered. Unfortunately, as in most of these economic considerations, the parameters which have been introduced all have their margins of uncertainity, not the least of which is in the lethality of the weapon itself.

It may be of interest to know that this system has been compared with a petard system of a ring of missiles exploded automatically from the ground. In initial costs, the ring of missiles wins hands down but the great difficulty of the system is that in consecutive raids it would be extremely difficult to 'reload' the system. Thus a petard system loses against consecutive raids, whereas even against formation attacks, quite a conventional gun such as the L 70 shows reasonable kill probabilities against both high speed jet attacks at 600 knots and more conventional attacks at 250-300 knots coming in overland at heights right down to 250 feet."

Dr. Rumbaugh: "I would suggest that when you talk about defending convoys or tanks or field army installations and about defending cities, you are talking about two radically different problems. If the attrition rate climbs a little above 10%, I believe, against relatively small targets it becomes very discouraging to the attackers. That was true, I believe, in submarine warfare for example where as important a target as a ship was being attacked. But when you get to attacks on cities you have to reach an attrition rate of 60 or 70% to discourage the attack finally. We should keep this in mind in the discussion. There is a tremendous difference in the final result we want to achieve."

Gen. Marshall: "I agree that the problems are so unlike, tactically economically and logistically, but it is not until you spell out the differences in detail that you can see what the problems are, as a whole. We are not looking for one weapon which will be equally applicable to defence on both the Z.I. and the field army, because such a weapon would not be supportable by the field army.

I, for one, do not believe that the low level attack is a decisive threat to a field army until it has settled down to a trench system, and even then the threat can be defeated. The Chinese certainly found a way to defeat it by digging in and by working out a maze of positions so complex that it was impossible to tell where any of their personnel were located. Their surface trench system had great tactical depth and was used only as a sentry system, whereas their troops were dug in behind the ridges. Events in future war may well come to something half way between the system of defence we used, which was really quite amateurish, and the system the Chinese used, which was far too sluggish and rigid."

Mr. Ross: "I agree with Dr. Rumbaugh on this question of attrition rate. It seems to me that the point which has not yet been made clearly is the difference between the situation in which the enemy is using conventional bombs and that in which he is using atomic bombs, and the difference of the attrition rates which these two situations call for.

The other point I want to stress again is that of assessing the threat. We are arguing along the lines; is low level attack possible or not? I believe this is not the main question. Low level attack is obviously possible if anyone wants to do it badly enough. What we really need to do is to assess the threat much more realistically. What is the size of the raid? What is the rate of arrival? These are the things which say how many weapons you will need, and will determine the cost. We have to settle these points and define the threat more realistically before we can even begin to discuss the economics. This applies both to the field forces and to this country, and the cases of conventional attack and atomic attack must be separated."

Col. Macklen: "The field army cannot afford a large complicated piece of equipment firing thousands of rounds of ammunition. It is difficult enough already, to provide sufficient logistic effort for the ammunition for the 40 mm guns. Even if we improve methods of supply, we do not see that we can make an order of magnitude improvement. If, then, we have weapons with a higher rate of fire then we shall probably have to use fewer of them. In turning from defence of the home base to defence of the field army, we have to bear this in mind. The weapon for the field army must be mobile, it must be simple to maintain and it must not require too great a skill in the technical services to keep it in operation."

Maj. Maskell: "I would like to suggest what I think is the difference in the weapons systems. If you are concerned with an attack on a particularly important vulnerable point, then it is conceivable that you will get a low level atomic attack. In this case you are very concerned with bringing the aircraft down and you should be thinking of 90% attrition rates. But on the other hand we may have many vulnerable points which are not very important and here all that is necessary is to discourage the attacks. In the field, I think what happens when you discourage low level attacks is that you make the effectiveness of the aircraft very low. In the home base, you want to discourage low level attacks so as to force the aircraft up where you can deal with them.

I would go back to balloons again here. It does not matter whether balloons bring down planes or not, but balloons are a relatively inexpensive device for pushing aircraft up to a level where it can be dealt with. This is true, also, of smoke in the field. It discourages aircraft from coming down to those levels where they can deal with the small pin-point targets of the field army. So it seems to me that where our research is required in this problem, as opposed to the problem of the serious attack, is what does it take to discourage the air force from coming in at low level."

Prof. Holt-Smith: "In the diagrams we were shown in Henry's speech, we were shown the cost of defence per thousand yards of perimeter. But the perimeter itself was not closely defined. In certain circumstances, it might be the bomb release line. In this case the perimeter itself is a function of the height of attack, and in the case of simple short-range weapons the change of effective perimeter with the height of attack becomes significant. This would bias the curves at the lower heights in favour of the simpler weapons.

I feel that there is a certain amount of defeatism about the difficulties of defence against low level attack because it will, of necessity, be less efficient than defence against a medium level attack. But, in a similar way, so will the attack itself be more difficult and what really matters is the relative figure of merit, that is the success of defence versus the success of attack as a function of height. In other words, if we fail to hit an aircraft and the aircraft fails to hit the target, the score is none all. If, therefore, we accept the relative efficiency of defence and attack as the thing that that matters, we can begin to look at the problem fundamentally and see what other factors affect this relative efficiency.

Surely, the operation of defence and the operation of attack are precisely the same. It is the problem first of target location and second, of weapon control. What are the relative factors for attack and defence which may be influenced by height? An essential difference is the cramped space and general limitations of being in an aircraft. This favours the ground, irrespective of height. A second factor is gravity, which works one way only. Gravity limits the defence at high altitudes more than it does at low altitudes. It would appear, therefore, that, fundamentally, with optimum equipment the efficiency of defence ought to increase as the height of attack decreases. Why can we not achieve that postulate? Is there any fundamental reason why the optimum equipment should not behave in the way I have indicated?

Mr. Henry: "I should like to extend a little what I said earlier. As has already been mentioned, it is necessary to examine the defence in relation to the target being defended. At ORO recently we have placed the emphasis on the defence of the ZI against long range atomic attack.

On the assumption of this kind of attack we must agree that no enemy is going to come 2,500 miles or further without an extremely determined attack, and he will come in where he has the greatest probability of dropping the bomb. If you tackle these calculations from the other end and make plots of the probabilities of dropping atomic bombs on given places, the picture becomes quite fearsome. You have to run through a series of games on this and observe what would happen with particular defences and particular types of attack. Our conclusions, which are very tentative so far, indicate that from the point of view of local defence, it is better to put as much defence as possible around a few targets and give token defences to the remaining areas. The necessity to defend as much as possible of the industry and population and strategic air bases have greatly influenced our calculations."

Mr. Barham: "What Henry has said ties in with our own line of thought to some extent. We came to the conclusion that it seemed incredibly expensive to provide a very high level of defence in all the vulnerable areas of the the UK. The ultimate course of the investigation is to take a certain sum of money and try to work out how many areas one should defend at a high rate, leaving the other areas to be defended at about the 10% or 15% level."

Mr. Henry: "In our study we are also trying to include defensive means which are not essentially active defensive means. In other words, if you feel that you cannot defend a certain factory, you might perhaps stockpile a year's supply of the factory's output. Of course, you can consider a number of other possibilities and stockpile machine tools, say, or put some factories underground or develop duplicate manufacturing facilities."

Mr. Geeson: "I would like to make two or three points. The first is that we have not really discussed to any extent how the Air Force can help us in this low level defence by actually attacking the enemy on his own bases. It might well be a reasonable method of reducing the enemy air offensive.

The second point was raised earlier when the problems of complexity of weapons and supply of ammunition was mentioned I shall not say anything about complexity since we shall be considering the point later in some detail. But as far as the supply of ammunition is concerned, when we may be thinking of guns which fire about twice as fast as at present, I think it is fair to say that some of the work which Mr. Mound has been doing recently may be of great help here.

The third point is that we want to know more about the morale effect of various things. We have, for example, spoken of balloons and possibly we have raised a few false hopes. I think it is important to realise that a great deal of the effect of a baloon barrage system is due to what the pilot expects to happen to him if he flies through it. We have some evidence from the last war of the effect of the balloon barrage on the pilotless missiles which actually flew through it. The actual number of missiles destroyed by hitting balloon cables was of the order of twenty or thirty, while the number of kills by guns was of the order of two thousand. The effect against piloted aircraft seems to lie in the fear that can be put into the pilot, and it may well be that we can get more information on how that fear that can be instilled. The same sort of thing seems to apply to light AA defences. I imagine you do have to kill a certain number of pilots to make the remainder respect the light AA defences, but at the same time the very existence of tracer, flashes in the sky, even fireworks, might well help to reduce the morale of the pilot and improve the effectiveness of the defence. We should like further information on how we can boost this morale effect of our defences even if we don't kill many people."

<u>Dr. Rumbaugh</u>: "I think most of the points have been pretty well covered. There is one thing I would like to see continual emphasis on and that is the relative cost of the long range defence versus the type of warning system that will go with it. We may lose by putting too much emphasis on a relatively smaller number of very complex radar outfits let us say, on high towers for example, when perhaps some simpler system with more units might give all the early warning we want. If we can establish at the early time the general course and direction of the attack then we have most of the information we want because we obviously must expect some change of course, some evasive action. So I am disturbed to see these very high performance equipments which give the precise information of the type needed for fire control put out on the peripheries, when really that sort of thing is needed only at the gun."

<u>Col. Boehm</u>: "Most of what has been said points towards increased complexity with guns. The radar equipments, fire control and early warning are most effective against high altitude attack. We can only afford so many of these equipments and we may therefore have to become much simpler in our defence against low level attack. We certainly cannot produce complex equipment for all forms of attack in all our home bases."

<u>Mr. Ross</u>: "I find this a very difficult problem because I cannot see a logical solution or a logical line we should follow at the moment. First of all, there is the high cost of the defence. From what we can see, we probably cannot afford to have about a 90% attrition rate for this country alone for high altitude attack. Then you need a low level defence which will probably cost pretty well as much. Then you have to repeat this for the field army, and then after all the enemy may use weapons of the V2 type, and none of this is any use against V2s.

Then I get rather worried by the fact that these defences are capable, or potentially capable, if we believe our figures, of destroying the enemy air forces many times over. I do not think any country has had to provide a defence that is capable of doing that in any form of warfare, and I do not believe it is necessary now."

<u>Mr. Sargeaunt</u>: "I do not think you can expect me to sum up but it is the object of the conference at least to outline the main lines of thought and work which will be of benefit in the next year or so. I do not know that I can do this here, but I should like to try to classify some of the points which have been made.

It seems to me that there are about four main themes. The first is, what is the exact nature of the threat. There is undoubtedly a gap in the defence and undoubtedly it will be exploited. But how will it be exploited? To what extent? By what means? I believe it is quite useless to do a lot of calculations until we are clearer in our minds and this will almost certainly mean going back to our Air Forces and to our exercises and in every way possible trying to visualise exactly what we are up against.

The second theme is the precise object of the defence. We have heard how the object of defence depends upon the target and is different under different circumstances. The great difficulty, I think, is to weigh one object against another, and to decide how the limited resources are to be divided between them. Here again I believe we need more clear thought and argument. Until we have made further progress in such assessment, I believe it to be largely a waste to spend money on research and development.

The third point is fairly clear I think; what points are to be defended. If the problem of low level defence is tackled against a general background, I do not see that there can ever be any definite answer. The problem must be related to specific theatres - even to specific points. What looks like a good answer for one point may be quite useless for another.

Behind the whole problem is the question of economics. In this, I believe, we are all in agreement, and we realise the importance of it.

I may be wrong in having placed these points prior to research and development on very specific technical answers. It has been said that there is a certain feeling of defeat among our technical people. I can confirm this for this country and, I believe, some of it can be attributed to the fact that these prior problems have, as yet, not received adequate thought. Unless these problems are simply stated and simply discussed it will be hard to make much progress."

Major Paper

Optimum Utilisation and Optimum Interdiction of Lines of Communication

The Chairman, Dr. O.H. Wansborough - Jones asked Mr. Mound to open the session.

Mr. Mound:

"I am going to talk only about the first half of this subject, that is the question of optimum utilisation. Later speakers will deal with interdiction.

The problem really divides itself into three separate parts. There are three ways of getting the best out of lines of communication. The first is to spread the lines as widely as possible. The second, having got the lines, is to move through them quickly. The third point: do not load the lines with anything that need not be carried.

When we in this country consider lines of communication we naturally tend to devote our attention to lines extending from this country to Europe, because these are the lines that will, in future wars, be the most pressing and the most urgent. So such thought as I've given to the problem does concern lines extending from the factory in this country to the forward areas in north-west Europe.

We have round our coast a comparatively small number of major ports and a rather larger number of minor ports. The same applies on the Continent. Again we have our major production centres and a number of smaller ones. It is fairly certain, I think, that if war comes, these ports, both in the U.K. and on the Continent will be the first to be attacked, and we have to consider how far we can spread our lines so that we have sufficient flexibility to overcome the effects of that attack. During the last war, we produced ports from practically nothing by using little coves and inlets around our coasts, and I think we should look for the same thing now. We must consider that we shall have to load and unload stores over beaches. We must be prepared in advance to route our goods through these lines.

In the same way, we must try to prepare for a bigger variety of lines in this country and overseas. Our road system is pretty complete and our rail system is also highly developed. There is the question of bridge crossings, and here we must consider how far they can be duplicated in an early stage. This applies particularly to the Continent, where the lines are more limited.

Now the question of speeding up transit. I think the position is reasonably satisfactory when the goods are on a ship or in a road vehicle or railway truck. Where serious delays are introduced is at the transfer points where, for various reasons, the goods come to a standstill and may even go into storage for a period. This can be one of the bottlenecks in the supply line, which is receiving much attention, but there is much more to be done. We have to consider whether we cannot eliminate some of these stopping points. In civilian life, if you order materials from a certain agency, it does not necessarily follow that the goods will pass through that agency, and I think that there is no reason why we shouldn't make use of this system by having our goods delivered direct to the ports from the place they are produced. There is no reason why some goods should pass through the army storage system at all.

We must consider our means of transport. Whether we are operating here or on the Continent there will be a mixture of army and civilian transport. The two cannot be separated. It is necessary to consider all means of transport that are likely to be available and see how they can be modified to simplify and to speed up the handling and transport of goods. Among points to be considered are the standardisation of road vehicles and railway vehicles, question of ease of loading and unloading and so on.

Another very important question is that of manpower. There is an ever growing need for men in the forward areas, and in the home land as producers. We just cannot afford to have too many men in the handling chain. Work is going on in this field. We are developing various mechanical aids which can help a lot, but there is a tendency to be tied to equipment developed for civilian uses. This is generally developed for a special purpose and is not by any means ideal for military use. Here again, we must produce our own specifications and make the equipment that we really need for our work.

We must go much further in the methods of handling stores over beaches. There is no doubt that at present the port is the ideal way from the point of view of speed and effectiveness, but I am by no means certain that this need be so. Although in the last war the number of beach landings was comparatively small, we did have an organisation that was quite effective. I think we can go a lot further and I see no real reason why a fully developed system should not be equal, or at least nearly equal, to conventional supply through ports.

Another factor which is quite important in the rapid handling of goods is the size of the load. There is a tradition that all loads should, if possible, be capable of being handled by men because, in certain theatres, the man is the only means of transport. That is all very well in its way, but in the majority of theatres we shall not have to depend on manpower only, and should develop our load sizes to be the most economical for mechanised transport with the proviso that if that form of transport breaks down one can still revert fairly simply to the man load. I think our present policy of trying to bring loads down to 40 or 50 lbs must go, and we must consider loads of something between half a ton and two or three tons, depending on the type of transport.

Now to my last point, that of carrying necessities only. It is an alarming fact that all too often when we are trying to carry goods we are, in fact, carrying empty space or unnecessary weight in the form of packing. One of the major items is ammunition and, in general, for every 100 lbs of ammunition carried there is about 20 to 30 lbs of packing. This reduces the effective loads on lorries, it takes up space in all forms of transport and when it gets to its destination it is of no use to anyone.

We are working on this problem and trying to reduce the 20 or 30% to something less than 10%. It's a little early to say yet, but we think we have some means for doing this. We shall be able to put rather more into our ships and a lot more into our road and rail vehicles. We think the form of package which we are trying to develop will, in fact, be more useful to the soldier in the front line when he gets it there, and although the packages will be considerably bigger than they were before they are still reasonably easily handled. We are thinking in terms of 500 lb packages of ammunition which would normally be transported mechanically, but can be handled if necessary by two men over rough ground in forward areas.

There is a modern tendency in unit loading to use the industrial pallet, a lot of stores neatly strapped together. It's a convenient way of handling but it is a very wasteful of cargo space, particularly in ships because the pallets take up a lot of space. We are doing work here aimed towards keeping the unit loads but getting rid of their pallets.

As a final point, I think we can make quite a saving in transit time by distributing the nature of the goods more widely, that is by not having too many separate dumps of different kinds of stores. When it comes to collecting goods for forward areas one will not then have to go to too many places to get them. There is a safety factor in this as well because the loss of one dump does not necessarily mean that you lose all of a certain commodity."

The Chairman, Dr. Wansborough Jones then invited Major Maskell to speak.

Major Maskell: "The Canadian Army is not in the same position as the British Army or the U.S. Army. We do not have the same responsibilities for developing, protecting and using a line of supply that either the U.S. or the U.K. have. In general, we operate within an American framework, as in Korea, or within a British framework as in N.W. Europe. This means, from the operational research point of view, that we have not been required to study this problem in any

overall way. However, I do think that the problem is one that does reach right into forward areas, and so we do get a bit concerned about that end of the line of communication which touches the tactical region. We have come across this problem from the point of view of interdiction rather than of utilisation.

We have been studying the battle of Suomassalmi in the Finnish war. This was an unconventional tactical attack and an unconventional exercise of interdiction by the Finns against the Russian assault at the beginning of the winter '39-40. In this instance, in a fairly isolated spot in the middle of the waste of Finland, a Russian division attacked along two axes, one entering Finland from the east and the other from a 'jog' in the international boundary from the north, impinging on the village of Suomassalmi. There, they were to cross the lake and proceed along the main road across the wastes of Finland. The Finnish reaction to this was not a frontal attack, but an attack on those two axes at distances varying from two to twelve miles behind the positions established by the Russians on the lake.

The whole thing was extremely successful, and a second Russian division sent to relieve the first was also dealt with in the same way and the outcome of the action was a decisive victory for the Finns. The advantage of this from the tactical point of view was that there were many points of attack along the flanks whereas, for a frontal attack, there would have been only a few points. Of course, this is not possible on many occasions when there are not any exposed flanks, but it does happen on some occasions that interdiction can be carried out from the ground. In this particular case, air power was not involved at all.

The other aspect of our study of the Finnish campaign which is relevant to this topic is concerned with a later stage, when the Germans and the Russians were at war. This drew the German troops in Norway and the Finns into the war in the middle of 1941 and a three year campaign followed. The Germans and the Finns attempted to drive across Finland towards the Murmansk railway, which runs north and south along the White Sea down to Leningrad. In the northern part of Finland there were three corps, two German and one Finnish, separated almost completely by very barren and impassable ground. For about two or three months they were able to take the offensive, after which things became static. Both Finns and Germans attempted to raid and to cut the Murmansk railway but without much success although they had, no doubt, a great deal of experience in this type of interdictory activity.

The Russians, for their part, became very active, about the middle of 1942, in doing the same thing as the Germans and Finns and troubled them very considerably. It led to the establishing of German protective forces to protect their own lines of communication, particularly the Arctic highway which ran across Lapland to Petsamo, and the whole exercise became one, not so much of static war, as of guerilla warfare behind both sets of lines."

The Chairman invited Dr. Tyson to speak next.

Dr. Tyson: "I would like to continue with some of the subjects raised by Mr. Mound. Our interests are closely parallel to those of the British. Our problem is one of overseas supplies and may seem, perhaps, to apply to overseas areas. We have been particularly interested in this question of the relative utilisation of beaches and ports for the disembarkation of supplies.

Obviously, we shall have a situation different from that which prevailed in World War II. First of all, the requirements for supply have, unfortunately, gone up rather than down. The initial equipment which must be sent in with the men has gone up by a factor of about 50%; the rate of re-supply, which is governed by the consumption of fuel and ammunition, has apparently gone up by the same order of magnitude. Thus we will be faced, in any future war, with the necessity for a greater rate of supply and a greater total supply. The most important point is the vulnerability of our lines of communication, and the new factor here is the atomic weapon. This seems to indicate that we must use first operations to a much greater degree than before and we must rely on small self-supported forces to a much greater extent.

We have done some calculations concerning the effects of atomic attacks on ships. Obviously, this can be carried out only to a limited extent because we do not know in advance what level of atomic attack will be directed against us. The expected loss within ports will presumably be simply proportional to the utilisation of the ports.

There is some information available on the effects of atomic weapons against ships carrying out unloading operations in the Government publication 'The Effects of Atomic Weapons". We know from that, that whenever an atomic weapon is used, we can expect ships to be sunk roughly 1500 - 2000 ft. away from ground zero. However, at 4000 ft. from ground zero it seems reasonable to expect that ships will be so seriously damaged that unloading operations on those ships will be stopped. In addition to flash damage there is the greater risk of contamination. It seems that out to distances of about 3500 ft. from ground zero the dose of radio-activity will be sufficient to incapacitate any sort of craft which may be participating in the operation.

Now to cut down our losses to a reasonable minimum we could disperse our ships so that they were no closer than 3,500 ft. or 7,000 ft. apart, the latter case giving the irreducible minimum in which only one ship was affected by atomic attack. This would probably discourage the enemy from using his atomic weapons on such targets. Could this sort of dispersion be achieved, and how much would it cost us in terms of our own effort.

We have looked at the unloading rates that can be expected from the lightest craft which are currently available to us, and we have found that these unloading rates are extremely insensitive to the actual distances the craft were required to travel, with possibly the exception only of the 2½ ton DUKW of World War II. It appears that the reduction of lighterage effort obtained by decreasing the spacing between ships is only about 0.3% for each 1000 ft. reduction in spacing. On the other hand, the damage to be expected in an attack increases very considerably with reduction in spacing. So, theoretically at least, the passive measure of dispersion offers a very good promise of protection. Practically, of course, it is another matter and hinges on the availability of beach sites. Another practical difficulty is that of communication and control of the unloading operations.

There have been a number of new proposals which I will discuss briefly. There is the very large size DUKW which has been developed by the Army. This has a capacity of 60 tons at maximum range or 100 tons for a short haul. Another idea which has been proposed is the aerial 'tramway' from ship to shore, and one of these has been in operation in the United States. This system has the advantages of being relatively insensitive to features of terrain and of relative insensitivity to enemy attack. Finally, there is the use of helicopters for unloading ships. Although trials have been carried out, I think the concensus of opinion is that this method is still a long way off, except in the case of specialised assault operations.

Finally, I might just mention the problem of dispersion generally. We have been trying to study the problem from a general point of view to see if we can determine the optimum dispersion of depots and dumps. Where is the 'break-even' point between increased cost of operation and reduced vulnerability to atomic attack? What are the details of the best method of dispersion?"

The Chairman called on Mr. Kaye to speak.

Mr. Kaye: "We have done some work relating to the supply of forward areas from the army zone and the problem which we were considering was the movement of supplies to the forward troops more or less on a day to day basis. It is generally accepted that as much movement as possible should be done at night, but it may very well happen that you may have to supply by day. So what we consider is the movement of vehicles by day in a situation where the enemy has air superiority over the area.

From operational research in the last war and from data from Korea, we came to the conclusion that under the present system something like 500 tons of supplies is needed per division per day. On the other side, from the study of air interdiction, it appears that, on the average, the number of sorties which the enemy would be likely to carry out per day against the divisions supplies is of the order of 25 or 30. On occasions, it might go up to 50.

For our 500 tons of supplies we can expect something of the order of 200 vehicles per day moving up the MSR. There are about 50 sorties a day, and on each sortie the aircraft can be expected to make about 4 runs. So that, in theory, there is the possibility that every vehicle will be attacked during the day. We should therefore consider seriously the possibilities of protection of the vehicles.

The first possibility is to increase the spacing of the vehicles, so that when the aircraft comes in, it can hit at most only one vehicle and does not have the chance of hitting other vehicles near to it. The second possibility is that of camouflage and deception. It is comparatively simple to calculate, for the types of weapons being used, how far apart the vehicle must be in order that one only will be picked out as a target at each attack. We studied the weapons available, machine guns, cannons, rockets, small bombs, Napalm etc. and came to the conclusion that if you have a spacing of 200 yds between vehicles, then you are fairly safe from this point of view of offering more than one at a time as a possible target.

On the other hand, we took note of the general conclusion, accepted by each of our three countries, that the packet system has much to recommend it. In this, you have a small number of vehicles moving together so that they are not so easily spotted. This gives a possibility of practising deception because if you have only a small number of vehicles as a target, it is possible to lay out decoys consisting (apparently) of small numbers of vehicles in prominent places for the enemy to attack. It is shown by studies made in the last war that anything in a prominent position is likely to be hit and, if it remains there, it will be hit time and time again. Also, with movement in small packets, another possibility is the use of smoke cover in a much cheaper way than is possible with convoys, because you can have it in patches, rather than as a complete continuous cover over the whole convoy."

The Chairman then asked Colonel Macklen to speak.

Colonel Macklen: "I should like first to make a few remarks on what we have just heard. We have done some work in BAOR on vehicle movement. We have arrived at the fact that, during daylight, merely from the traffic control point of view, it is necessary to move the vehicles in packets. The Army cannot, of course, divide its vehicles neatly up into blocks of five because there are tactical entities which must travel together. The average block works out at about 10, and the scatter is between 5 and 25. The spacing for normal daylight movement is 80 yards, and the speed is about 40 miles in two hours.

We have come to the conclusion that in the event of total enemy air superiority, daylight movement in the divisional areas will be extremely difficult, and it will not, in any case, be done in convoy. It would be done by free runners which would be despatched at varying intervals along the route, rather like the American 'Redball' systems and they would travel as fast as they could. At night only would you use a convoy system and then you would use a vehicle spacing of about 15 yds. and a much slower speed. The speed would be about 15 miles in 2 hours.

One interesting point which does arise is that the supply columns need accurate meteorological forecasts since it is possible to do a very large amount of daylight movement in Germany because of the weather. I would say that in Germany that on about 50% of days you could move during daylight, at least up till mid-morning, and it might also be possible again towards the end of the day.

We have, in BAOR, practical considerations as well as theoretical ones, and we have been asked to study the problem of the L. of C. which we will inherit. We inherit this L. of C. from the civilian economy. Now if you inherit an L. of C. from a civilian economy, and graft on any system on to it, it is almost inevitable that in peace-time questions of civilian economy will come first, and the question of vulnerability is scarcely considered at all. Thus nearly all our lay-outs, depots etc., are designed with the object of saving money, and not with the object of making them less vulnerable to attack.

We have, of course, considered the effects of atom bombing on the L. of C. The conclusion we come to is that we must get away from the major ports, where all supplies come through a restricted area (and this is especially true of the constricted European ports) and use either a large number of small ports or beach landings. This policy, of course, increases the difficulties of the actual movement of stores because there is much more handling, and the routes and communication centres are not so well equipped.

A serious point in all these considerations is the problem of labour. Depots will have to be manned to a large extent by locally recruited civilian labour - we just have not the British forces to do it if we want to keep anyone in the fighting line. We are extremely worried about the reliability of civilian labour, especially when their homes are under continuous air attack. A continuous air attack on the homes of the labourers is a method that could be used in order to make the L. of C. very difficult to work. In this connection we are looking for evidence of what happened in Antwerp in the last war.

Another method of attack on the L. of C. is the attack of any defiles which may exist in it. All our supplies have, in fact, to come across three bridges. We have worked out that, using ordinary bombs, it would require about 200 - 500 sorties by I.L. 28 aircraft, or 60 - 140 sorties by T.U.4's to destroy the bridges. These figures are not very illuminating unless you can find out what effort the enemy is likely to have available for the task. But as a rough estimate we think that the enemy could, if he wished destroy the bridges in about 5 days, even though they may be defended by light A.A. We are now looking at methods of making the task require a greater effort, for example, by using smoke cover.

On questions of defence, we have tried to put ourselves in the enemy's shoes and have asked ourselves 'What would I attack first?" We think that he would attack either items in short supply, if he knew what they were, or common user items. And the most likely common use item is petrol. In order of priority our supplies are approximately ammunition 60%, petrol 30%, and all other stores 10%.

Now the petrol supply is, in our L. of C. and I presume in the U.S. system too, almost a complete system in itself. You have petrol depots instead of Base Ordnance Depots and in the FMA the petrol depots each contain about 50 tons and are about 50 yards apart. These, of course, extend over a very large area. For fire security risks the ground between them is cleared so they stand out clearly and it should not be difficult for the enemy to find them. We do not yet know how vulnerable these stacks are and the only evidence we have comes from an 'incident' in which someone poured one jerrican of petrol over a 50 ton stack of cans and set fire to it. Every can of petrol either burst or leaked under pressure and the whole stack went up. Some of the cans were thrown a distance of 70 yards, and 50 yards was quite common. The cans were still burning when they landed.

We do not yet know, however, how difficult it is to set a stack alight by means of bombs, rockets, shells etc., but we are hoping to get some evidence from trials.

The ammunition depot is another interesting case that we have thought about. Here again we are handicapped by lack of facts. At the present moment an ammunition depot is laid out, not only to make handling easy, but also to make stores accounting easy. The question of vulnerability is not considered, so that you may have a situation in which the total theatre reserve of some particular type of ammunition is stored in one small area. It can

thus all be destroyed by an attack or succession of attacks on that area. We suggest that stores should be distributed so that in each shed or in each area there is a multiplicity of types. If possible, there should be a divisional slice or a fraction of a divisional slice in each shed. This arrangement will also help in estimating the effect which any attack has had.

In the defence of the depot or of a defile, we are, of course, thinking of all conventional methods. We are also replying on concealment. Some of these things can be concealed quite well. We have been worried by one fact about ammunition in this respect. It has been the usual practice to split ammunition into fairly small packages in the forward depots and to conceal them in woods. We think that the ammunition itself may not be particularly vulnerable to atomic attack, but we wondered whether ammunition in a wood is not very vulnerable to such attack, simply because if the trees are blown down it may take a considerable time to get the ammunition out. This might be quite a good way of attacking a concealed depot or assembly of depots in a wood.

Our thoughts on the problems imposed by the existence of the vulnerable bridges in our supply system run on these lines. The first thing that occurred to us in that under the present system we are not making the fullest use of the bridges themselves. The Corps or divisional transport is crossing and re-crossing the bridges at night and although the total traffic may be heavy, the useful load carried may be small. In fact the greater part of the total load is formed by the transport system itself, and this contributes nothing to the supplies. We have wondered whether it is possible to extend the FMA so that it includes the defile. Getting stores across the defile then becomes the responsibility of the depot commander but he, in fact, has an easier problem. Petrol, for example, could be sent across by pipeline. Aerial ropeways could deal with much, and these could be spaced out over a distance of about four miles, giving the enemy a much more difficult target to attack than the single bridge. Furthermore the depot commander has all day to get his stores across. We think the idea has possibilities."

The Chairman asked Dr. Rumbaugh to speak.

Dr. Rumbaugh: "I'm going to change to a slightly different topic. We've been talking about the defensive a great deal, and perhaps we have a defeatist attitude. Maybe it's good to start off pessimistically, but it is bad to extend the pessimism too far.

I'd like to talk a little bit about what we might possibly do in the way of interdicting the enemy. After all, one of the things that should be done in the opening phases of any war is to try to slow down the enemy rate of attack, and to extend his build-up time. I think this should be done because it's almost axiomatic that if war, or the outbreak of war, or the weight of attack is sufficiently delayed, the weight of force and of civilian economy and of means still does lie very definitely on the side of the Western powers.

Now, at the risk of rushing in where angels fear to tread, I'd like to show you a few diagrams (Figures, 1, 2, and 3) which are reminiscent of the whole problem of operations research. I'd like to start off by suggesting to you that since interdiction is, after all, only one of a great many problems that any army has to face, we have to decide on how we are going to spend our efforts, and decide on how much of it is going to go into interdiction effort in particular.

The reason for being very careful about how much effort you are going to put into interdiction is rather obvious from the Korean war and a number of other wars. To date, interdiction has largely failed. If interdiction had been successful in Korea, for example, why perhaps the war would have ended somewhat differently. The number of roads which the enemy in Korea could use was limited. His overland supply routes were actually longer than ours and rather primitive, and the air power we used in interdiction was essentially unopposed. But interdiction failed. That is why we have had to start right off with a rather pessimistic viewpoint on it. It's something which sounds fine in theory, but it must be looked at with a jaundiced eye. The amount of effort that we could put into interdiction, or into isolation of the battlefield, must be weighed against the many other things into which we might put that effort.

THE PRINCIPLE OF ECONOMY OF FORCE

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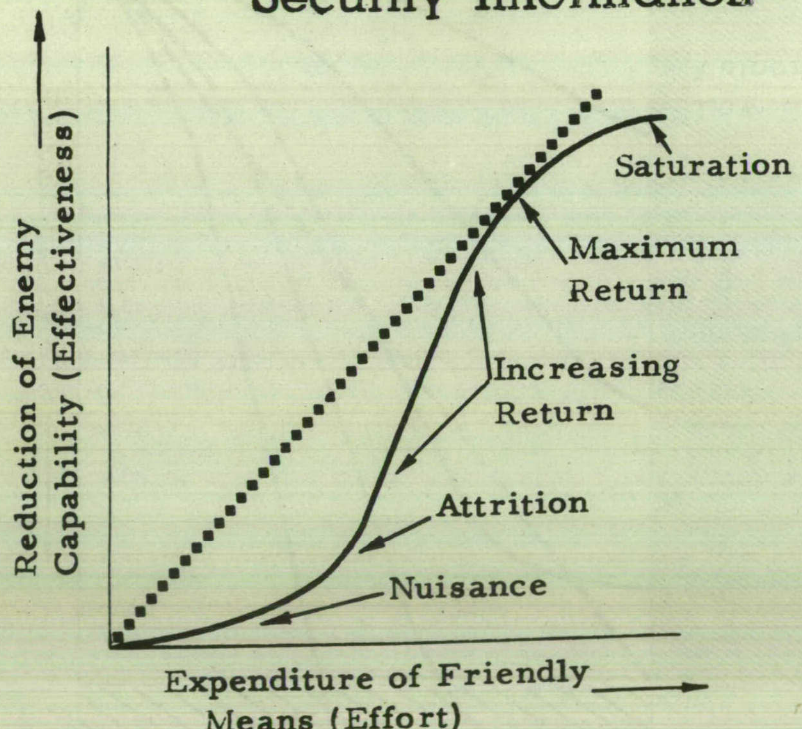

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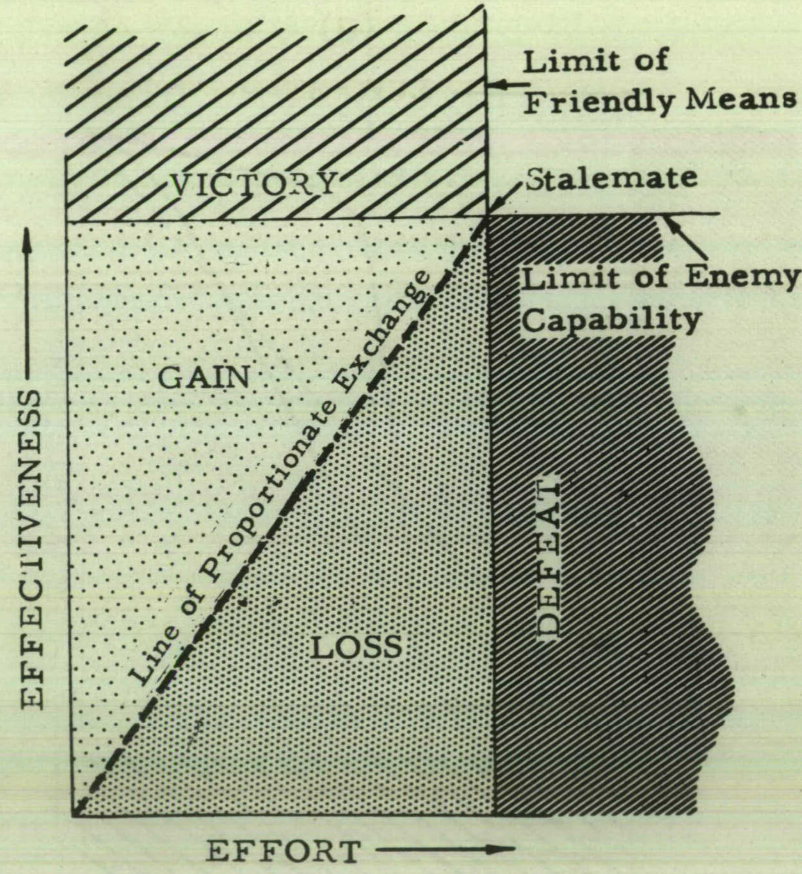

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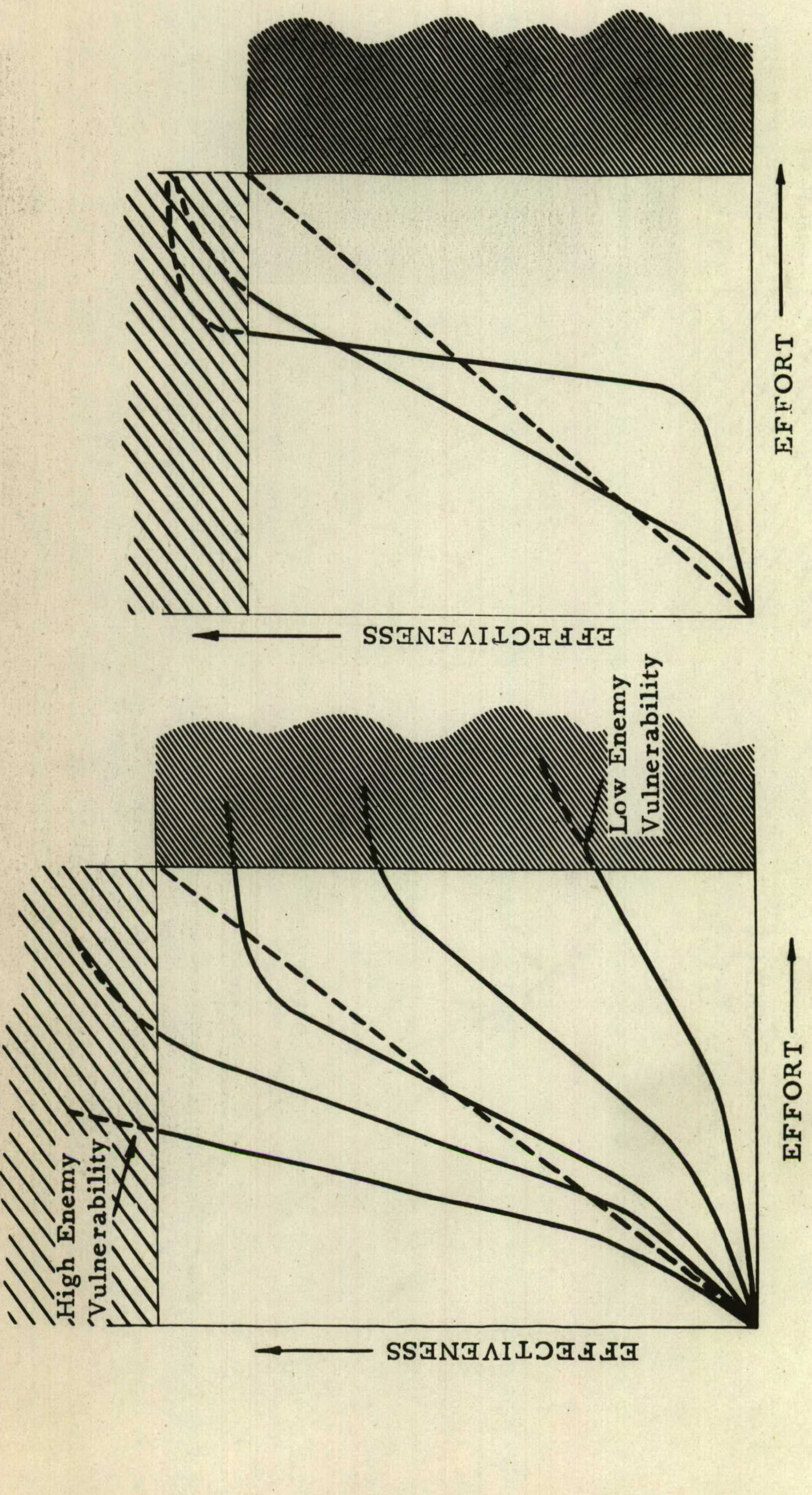

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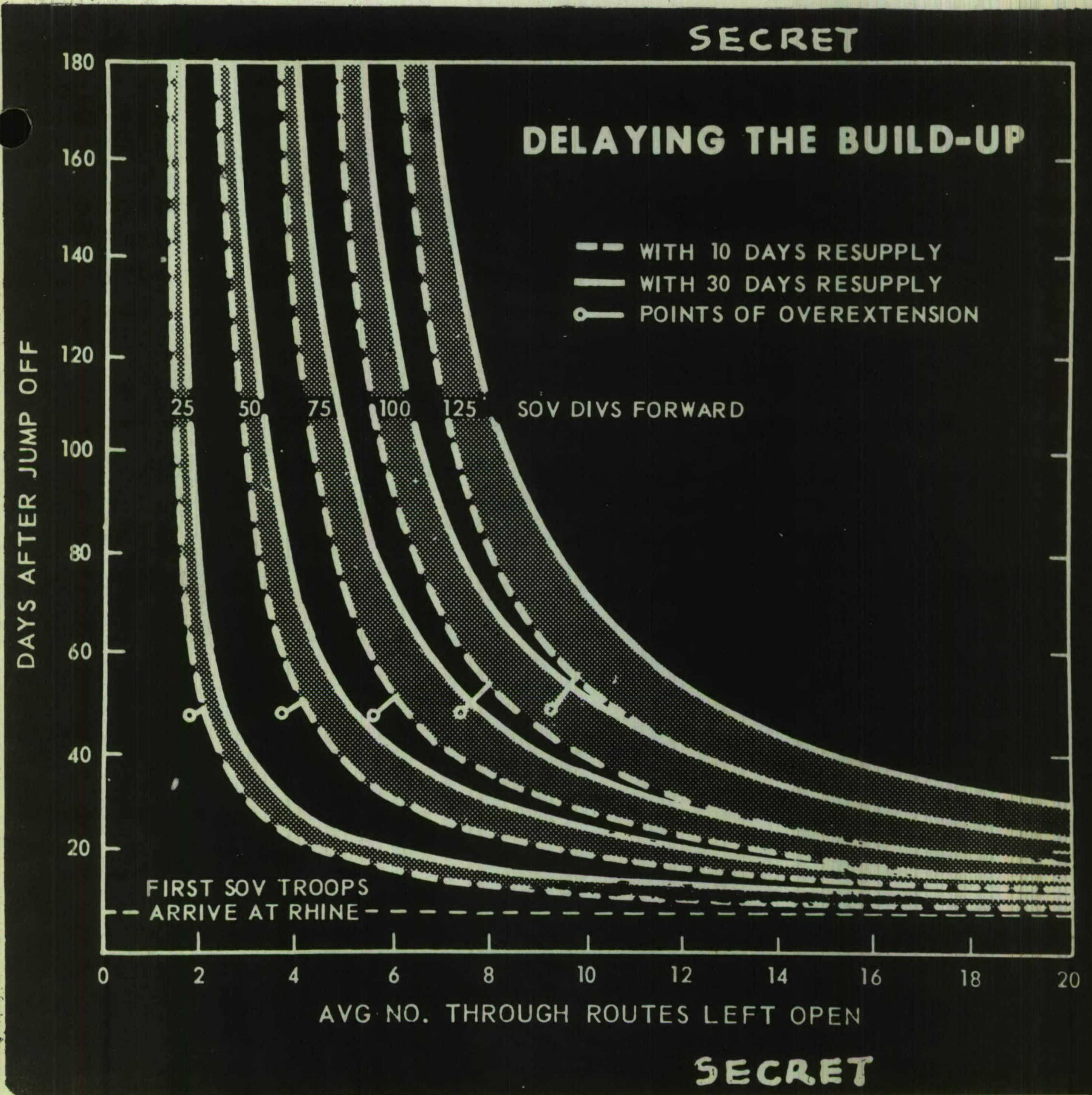

SECRET
DELAYING THE BUILD-UP
WITH 10 DAYS RESUPPLY
WITH 30 DAYS RESUPPLY
POINTS OF OVEREXTENSION
25
50
75
100
125
SOV DIVS FORWARD
FIRST SOV TROOPS
ARRIVE AT RHINE
DAYS AFTER JUMP OFF
180
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
AVG NO. THROUGH ROUTES LEFT OPEN
SECRET

But, I threatened to say something about the fundamental problem of military operations research.... I state the problem as one of conflict between friendly and enemy forces in which we can either consider the whole war or only a campaign, or in which we can consider some segment of enemy capability, or in which we can consider only a local battle. In other words, we can talk about air superiority if we want to, or we can merely talk about the enemy's ability to maintain a single bridge across a single river. We can break the conflict up in any way that we wish, and talk about some segment or collection of segments of any of the capabilities opposed.

If we do that, our problem is this. Friendly effort runs from zero to a point where it's all expended in what will have to be called defeat. You haven't got anything left, you're done - and that applies to a segment of capabilities or to a local battle, or to one phase of war, or to a campaign just as well as to the whole effort. In sum, we are opposing an enemy, and our problem is the reduction of his capability, and - what is a considerable factor - his will to use his capability. It might be called the effectiveness of our attack, or the reduction of enemy capability - which starts off from zero and goes up to a point where the enemy's capability and his will are reduced to zero. That is the victory line. This applies in case of friendly effort equally well to a segment of enemy's capability or to a whole war.

Now our efforts or our means can be large, larger than his, or they can be smaller, so that the relationship of the two forces gives a rectangular rather than a square display (see Figure 1). Think of a battle as going on, and the exchange ratio as favourable to us only when we lose a smaller percentage - of whatever it is that is being compared - than he does. Consequently, we have a line which we might call the line of proportionate rather than equal exchange, and we can say that anything that falls above this line can be considered as gain, anything that falls below this line can be counted as loss. Then of course, if we extended this line, ultimately of course, we get to a point of stalemate. So the problem then of operations research might be stated as to keep on the GAIN side of the line.

Now an unfortunate thing about organizational effort at this moment, in my opinion, is that we have in the army three agencies, namely G-1, G-3 and G-4 all concerned with friendly effort. We know very well what effort we can put out, what our capabilities are; furthermore, we have all our national planning boards, civilian economy, and what have you, which furnishes us with countless figures on friendly means. For the other side of the relationship we only have one agency, namely Intelligence, or G-2 or A-2, whatever you want to call it, which is concerned with reduction of enemy capability - our effectiveness - and this is subject to a lot of uncertainty. So we have abscissae which are very well known and ordinates which are in considerable doubt.

It is characteristic of all warfare that, friend or enemy, the tone and the plan and everything else is laid out, for the replacement of normal losses, which reduce almost to a sort of nuisance value - a region in which the exchange rate goes along more or less linearly. To put it another way, the purchase effort for reduction of enemy capability, with the range of normal loss is near the foot (or ankle) of the curve (see Figure 1). I call it nuisance, or, at least, planned loss, because we have planned replacements for our losses and the enemy has replacements for his losses. It's only when friendly effort is extended beyong the planned replacement capability of the enemy that the effort starts really to take effect. It's then we get the attrition point, to the non-linear portion of the curve, in which we get constantly increasing returns. Our efforts pay off very greatly for a while, but presently we reach a point of maximum return and then we reach the saturation region and again we approach a linear exchange rate.

Well, now, the problem then is to find out whether this whole curve (see Figure 2) or what parts of it falls in the gain or loss regions. Actually, just to remind you of all the different things that might happen, the curve can start off slowly and then increase rather slowly and run into the defeat region because we have chosen to expend our efforts against a part or a segment of the enemy capability which is relatively invulnerable; or we may choose something that's quite vulnerable so that we can actually stay in the

gain region at all levels of effort and defeat a selected segment of enemy capability with little effort on our part. Of course, any number of intermediate stages may arise. (See Figure 2). Not only that, the points at which increased return on the non-linear part of this curve starts in, may be vastly different, and in fact they may be inseparably different. I've tried to illustrate this (in Figure 2) by showing one can get pretty fast returns at the start and then a somewhat slower return afterwards and reach victory with only a great effort. On the other hand, we may attack some segment of capability where we get very low returns for a while and then suddenly everything breaks up and it's over because the non-linear part of the curve suddenly begins to rise very rapidly.

Now, this looks very nice when we've drawn up graphs like this. In fact, we could say we are only faced with the problem of determining two points on the exchange curve; first, we must find out approximately where we change from nuisance to attrition, and second, approximately where saturation starts in. Given these two points we could pretty nearly draw the rest of this curve. After all it's primarily a sort of open 'S'. The unfortunate thing about it, I have to repeat again, is simply this: we know those abscissae very very well, but we know the ordinates very poorly all the time. Sometimes we are off by factors of two, sometimes we're off by factors of ten, and you can see immediately what would happen on any of these curves if we shifted the curve too much up or down. If the ordinates were off by a factor of two, it's fairly obvious we would have to be very doubtful as to whether some particular action should be undertaken. An action that we would say was almost certain victory, if subject to such an uncertainty, might be a very bad thing to undertake. That is why, when we talk about interdiction, I want to put an element of pessimism into my discussion. Interdiction has been talked about for a long time as a very effective thing, and yet, in it's most recent test case, where it seems to me it had everything in it's favour, interdiction has obviously failed.

We do have new weapons to approach this problem with, we do have perhaps a better way of planning we could apply. Perhaps our generalship has not been as it might have been. For example, during the war between the States,- I'll say the Civil War since I'm from the North - General Grant made the remark "I propose to fight it out along this line if it takes all summer." Now what he literally meant was, that at that time he was fighting down in the attrition portion of the curve and he was being criticized very heavily. But he knew that if he kept on he would reach the breaking point, marked by the "maximum return" section of the curve. It is that type judgement of course that the operations research analyst has to be able to criticise, or to tell other people how to exercise or promote. When we talk about interdiction, let's talk about it from that standpoint. In other words, not talk about scattered effort, but effort on some, if necessary, some very single point, until it is actually saturated. It certainly would do us no good in Europe, for example to scatter our interdiction effort by going around hunting the biggest head of horns until the big game is killed while at the same time letting all of the little game through - having no really good defence in any one sector. On the other hand if you are able to close off some one zone, to the extent that one rather small force could hold there, perhaps we could concentrate in the other sectors to fight effectively.

To get down to cases, if we start from the Z.I. and go through the communications zone and hence to the combat zone, we have, of course a large number of feeders which funnel down to a point where major means of transportation must be used. Then the routes start breaking up again. From Army Group or Army Front routes start branching out towards the Army and then again towards corps, and from corps they start branching out again towards division. We have something that's more or less analogous to the bloodstream I suppose, in which we have the main arteries and finally end up with the capillaries. Looking at a lot of interdiction in retrospect, it seems to me that we've never paid quite the amount of attention that we might be paying to the form of this hour-glass shaped network, and the crux at the stem. In Korea for example, the Yalu river actually is the area that's been neglected and it's been sort of tough on us because it does lie across main arteries. So, when I said interdiction has failed there under very favourable circumstances, you must remember that I'm talking really about branch arteries rather than main ones, so in that sense I have been unfair.

At divisional level we're concerned with the order of 300 tons per division per day, and we're also concerned with distances of the order of, let's say, 20 miles. If we try to apply an interdiction effort in a critical sense, at that point, we are talking about cutting all of a number of capillaries, or goat trails, or whatever you want to call them, that have a combined capacity of 300 tons forward per day for a distance of 20 miles. We're talking about livestock, pack animals, and people carrying burdens, minor vehicles, and all the improvised means that you can mention.

But to go back a little bit further, to corps level you come up to something like 1,000 tons per Corps per day and we've extended this distance up to maybe 40 miles. At army level, we're getting back perhaps to 60 miles and up to let's say, 4,000 tons per day. Choose your own figures here. In fact, when we're talking about Army Group level, we're talking about magnitudes in the order of 15,000 tons per day and about distances which range from 60 to 200 miles. Now, as I've already said, in my view on the problem of interdiction, this cutting of capillaries fails, and is defeated by the enemy improvising means of getting supplies through. It's a little bit tougher for him to improvise at corps level.

Each higher level gets still a little bit tougher when it comes to improvisation. The arteries really run between Army and Army Group where supplies may already be in large depots. At the beginning of a war in Europe, that certainly would be the case. We wouldn't except the USSR to jump off to the West without substantial supplies in the army front level depots. Initially, therefore, cutting the LOC back of these depots would do no good. After a while, of course, it would do good but cutting forward of the main depots would do a great deal of good initially. And, of course, you want to get to the segment where major means of transportation are interdicted, not the minor means. I say that you can get any number of conscripts across the Elbe river in an improvised way, but the fact is that the improvised means cannot carry on forward. There has to be a link-up with the major means again, with a major highway, a railroad, or a canal, so you can focus your attention on interdiction carried out along whatever segment of a line you think you can saturate, and keep interdicted. But you can't scatter your effort over the whole front. This is a thing I've been trying to preach over here; make your capability advance your effort so as to produce saturation wherever you put that effort. Or else, let it go. If you can't do the whole front, then do some part of the front, do that part quite thoroughly.

This can be expressed mathematically if we simplify indefinitely, but it must be done with caution. Lots of people have tried to write down some sort of an electrical analogy or hydraulic analogy, for LOC. But it doesn't work that way because an electron, once a circuit is cut, automatically gives up and another back along the line takes it's place, and goes by a path of lower resistance; but when we talk about supplies, this doesn't happen, we have to re-route the whole damned thing. It doesn't happen automatically, and you can have a perfectly good alternate means sitting there in a parallel by-pass that may never be used. He may have a lot of low resistance paths existing, but if the enemy simply doesn't choose to use them and you attack those you are wasting your effort.

But I think we could write down an equation for a simple case in a way which shows the distinction between rewarded and unrewarded interdiction effort. Here, let us say, the enemy is trying to attack along paths in parallel. The threshold number of interdictory attacks per day is equal to the number of routes which the enemy is attempting to maintain, minus the number that he actually has to have, where the number that he actually has to have can be expressed as the number of the divisions that he has times the number of tons each needs per day, divided by the forward tonnage capability of the route. And then of course, the whole expression should be multiplied by 24 hours a day and divided by the number of hours that each route is closed on the average.

For example, Figure 3 shows the various numbers of active Soviet divisions which may be moved into and maintained in a forward area as a function of the number of routes kept open. We will suppose each division needs of the order of 300 tons a day and that supplies are moved over German national highways each with a capacity of the order of 4,000 tons/day. Figure 3 shows the

manner in which the number of Soviet divisions on the Rhine might depend on the number of routes left open in say, the British zone. It's of the order of 8 routes for 50 divisions. This is the threshold factor that must be calculated. The factors being related here are the number of Soviet divisions involved in an attack to the Rhine, the number of routes open to them, and the number of days it would take the enemy to reach the Rhine as a function of the available routes. How many Soviet divisions could be maintained forward of the interdiction or demolition line with 10 days or 30 days resupply is also shown - the former being simply just a minimum for a build up for further attack, and the other possibly a maximum. The enemy arrives more quickly at the Rhine after jump off across the Soviet border with 10 days of resupply. naturally, than with 30 days resupply.

There are of the order of 20 major through routes into the NATO zones of Germany, and leading towards the Rhine and the Low Countries and Channel ports. I think you can see (in Figure 3) that the hundred or so sorties it would take to affect closure of all but 8 of the routes for half a day or so is just of nuisance value. This level of effort makes almost no difference to the rate of build-up unless the enemy has an extremely large force of the order of 100 or more divisions. It also makes very little difference in their rate of advance to the Rhine. But, if we were to redouble the interdiction, - or not even redouble it, but add the next quarter of effectiveness, let's say, then the situation changes very very rapidly. Now we don't need to apply this interdiction effort across the whole front; we can apply it across any sector and still get a good idea of about the number of routes that have to be operated by the Soviet force.

Now, the curves (in Figure 3) have been plotted on an assumption as all curves must be, and this particular assumption is of uniform build up between troops and supply. This means that we start with zero troops forward and end up with the maximum support, and in consequence of that, we do come to a point that we can call the "point of over-extension", which I've indicated (see Figure 3) which occurs at the end of about 50 days, or 7 weeks. At that point the initiative in planning will pass from the aggressor to the defender. To this extent: If we were, let us say, allowing him to maintain 10 routes at that stage, and consequently of the order of 100 divisions, we could, by a sudden increase in the interdiction effort by a relatively small amount put him at a point where he could no longer maintain the resupply required for 100 divisions.

That's the danger point for him. This is the point of over-extension. But, if we started off with a comparatively small effort, and if we weren't able to suddenly increase it, we would not be able to catch him with his pants down.

I think that's about all I have to say about this general problem. I would like to point out this, that the hours of closure are small with conventional weapons and the effort required is very large, that with atomic weapons the picture changes quite radically, as is obvious to anyone who has read the unclassified publications. One difference between ordinary interdiction and atomic interdiction is that with atomic interdiction, the same crossing point may not be usable any more, which does make a vast difference.

There is another factor that comes in and that is that all armies and all air forces and all navies make their plans on experience tables, and in consequence, the rear areas and services do not have provision for a high replacement rate. The engineer capability for example to maintain an LOC in the Soviet army or in the US army, or the French army - choose anyone you want - is relatively marginal. A 50 percent loss of that capability would be extremely serious when you plan for only about 2 percent loss. Perhaps this is one of the features of atomic warfare that should be studied much more that we have studied it in operations research. Rear areas are now more vulnerable. Our capability in rear areas has to be restudied from a large number of viewpoints, not just from the one of balanced stocks, which certainly is very very pertinent, - and I could mention others. But we should study our capability to replace certain technical and administrative services on a different type

of experience table than the one we have now. It's perfectly possible that loss of engineering personnel and engineering capabilities through attacks on the LOC might be definitive in the war, rather than the loss of front line troops.

Well, those are just some rather rambling and random thoughts that I thought I might throw out here to close the rather formal part of this discussion, for whatever they're worth. Thank you."

The Chairman asked Dr. Cole to speak next.

Dr. Cole: "Much of what Col. Macklen said about the North applies also to the South and centre, and what we are working on in the centre is, in many respects, parallel to the work described by Macklen. I shall, therefore, only add some detail, and I shall not try to give a sustained presentation of our work.

I would say that, as in the case of the British, we have inherited a situation and this inheritance is not a good one. It is an inheritance of which the boundaries and the values are very well known to the Russians. We could, at one time, have pretty well worked out what we have now arrived at if we had followed articles which appeared in the French Communist papers and which ran as a series in the German paper 'Der Spiegel' giving, in some detail, our tonnage capacity, our vehicles, our service troops and the exact locations of the various segments of our L of C. I have assumed, therefore, that the problem of Intelligence which was discussed here this morning, may not, in the first phase of the war, be quite so much a problem as has been suggested. In a later stage of the war, Intelligence might be more difficult, but right now there is a standing joke which has appeared in a number of French and German newspapers that an attack against one of our largest installations could be made very simply by a bomber pilot flying down an autobahn (the only one in the area) coming to a geographical depression, and then dropping his bombs. That would be the end of that particular installation. I would suggest, therefore, that the enemy has a great deal of Intelligence of our main supply routes, the 'B' route, the number of transports we can put on these routes and, very probably, the exact location of our installations and an estimate of their vulnerability.

We have a problem somewhat different from Macklens in that re-supply from the zone of interior will, as geographical study will indicate, reach us later than re-supply will reach our allies in the north from their zone of interior. So we started out first to determine what our supply status really was. This would seem simple, but it was not. I estimate now that we spent three months determining our present supply status and this was only a beginning since supply status changed even as we tried to find out what it was. Having determined our supply status we accepted the rates of expenditure which were laid down in our various plans. These rates may or may not be correct, but they were the best estimates we could obtain.

Then, given the long period which we must wait for re-supply, we tried to determine what particular really critical items would first be in short supply. The next step was to determine to what degree our L of C, in the sense of transportation, was vulnerable. Here our problem was a little different from that of Col. Macklen. I would say, however, that we have looked at a particular segment of the L of C. This was laid on us by General Ridgeway when we briefed him and told him how vulnerable certain installations were. He asked a very pertinent, and very embarrasing, question; what palliatives could we suggest. We chose for our study the advanced section of the communication zone, and just forward of that, the rear area of the Army Group.

We looked at bridges and roads and then, using the present HQ estimates of enemy capabilities and assuming either enemy air superiority or, at best, parity, we came to the conclusion that in our particular area, the most vulnerable part of the actual transport system was the rail, not the rail bridge, nor the road, but the actual rail. This is because of the particular construction of French railway lines in the area we have under study. Since there is not a great deal we can do about changing the national policy of the

owner of these railroads we attempted to make recommendations, and these have actually been made, showing how you might salvage and restore the rail nets we are concerned with. We have, therefore, concentrated on restoration of damaged parts of the L of C and we have concentrated on what you might call passive defence. We have set aside much in the way of active defence because we, as the British, do not have the means for active defence available now or for the foreseeable future.

In the case of railways, and in the case of roads as well, we have concluded that it is necessary to operate at night and that the problem is now one of control. We have recommended first that the smallest of railroad stations along the lines in the segment I have spoken of should be tied in with air weather services and local radio broadcasting systems where weather reports are given. We figured out that on the basis of air weather service information as used in the last war, the air weather information should reach the smallest station, or a point where a convoy or train will be despatched, by darkness of one day so that proper traffic control can be exercised in order to take advantage of those extra hours which we anticipate will be available during much of the year. We get these extra hours because of the complexes of rivers we have in the area from which we get morning fogs lasting till 10 or 11 o'clock. It is not sufficient, however, merely to know what the weather will be. There must be a system for the immediate dessimination of this information, and a system of traffic control much more complex and widespread than we have now.

We have recommended that there must be an air-raid warning system, which is also tied down to the smallest of the railroad and traffic control points; that is, an air-raid warning system which extends only to the large depots and installations and to the main marshalling yards and train despatch points is not particularly valuable with the type of rail and road movement which we consider will be necessary.

We have attempted to determine what sort of improvisation can be made, quickly to repair rail cuts and damaged rail bridges. We have advocated an inventory in the immediate vicinity of certain bridges and rail lines. We have asked for an inventory of the labour available there, or within 2 hours of the point, and we have also suggested than an inventory be made by national authority of substitute materials such as stone, steel and wood which could be used for repair on the spot. We do not believe that with our present supplies, or with our present reserve of service troops and engineers, that we can actually maintain the road or rail system which may be turned over to us by a national authority. We must, therefore, despite the very real question as to the skill of local civilian labour, under the present circumstances expect to rely on this labour and on locally procured materials, whether we like it or not.

We have examined classes 1, 3 and 5 that is rations, POL and ammunition. It was fairly simple to determine what rate of loss we could sustain in these classes and still carry on the operation. We then came to classes 2 and 4 which contain items which are organic to a division in combat, or items such as engineer or barrier materials which may be issued to such units. Here we have run into a very real problem. We have suggested that re-supply of tactical troops retiring to the MLR may be a much more important problem, and certainly a much more difficult problem than anything of this nature that we have ever seen before. In the last war, the United States Army in Europe re-supplied a tactical unit within 48 hours on one occasion only. This particular tactical unit was only a reinforced rifle battalion. We have no experience in re-supplying units which have retired to the MLR bereft now of equipment and heavy weapons, re-supplying that unit while it is still in the line or while it is out of the line, for 24 to 48 hours only. So part of our recommendation in this whole question of vulnerability is to point out that the vulnerability extends to that point where you must actually re-supply and re-equip a unit in the line. We have made certain recommendations on the type of items which are absolutely necessary in re-supply if you are going to continue to conduct tactical operations and exercise tactical control even on an austerity basis. Here, I think, much work should be done. The absolute

minimum items needed to continue operations should be determined for each army. We must work out for our own army an SOP for re-supply of units which are in the line, or which must be returned to the line within a very brief time of, say, 24 to 48 hours.

Like the British, we have looked at the size of movements and in the case of trains we have recommended that the conventional 500 ton train should be cut in two, and that two of these trains should be used in night movements. Again, we have recommended that, instead of controlling the movement of trains from large sorting and marshalling yards and unloading such trains at a central point, there should be a staggering of unloading facilities all along the line. Instead of moving 5 trains into a marshalling yard, present small stations, even without sidings, should be capable of unloading trains. We have taken a look at such things as armour plating on railway cabs and a few other items of this sort. I think, however, when we had finished our study, that we had only two main recommendations to make. One of them was that the Allied Air Force had better keep the enemy from achieving even parity, and the other that we had better build up a stock in our own zone so large and so well balanced that no matter what the attack, we could still continue to function and support the army until such time as the L of C from the zone of interior begins to operate."

The Chairman invited discussion of the papers presented.

Col. Boehm: "I am new to this subject and I can only express a few scattered reactions to a broad subject of many facets. I rather like Dr. Rumbaugh's approach to the conclusion that if you want to accomplish any worthwhile results, you have to concentrate your force so that it pays off, and perhaps that might be a reaction to such a broad subject as this.

I was particularly interested because I have had some experience of the supply side of the Army's activities. With the requirements for handling and dispersal of stores, if necessary in the rear areas and along the L. of C. and with the increased complexity of weapons, the problem is being increased drastically. A point which would, I believe, be well worth study is that of the effectiveness of weapons in relation to the cost of increasing difficulties of maintaining stores and maintenance spares and technical skills (which are also vulnerable) along the L. of C. We have to measure this thing some way and we must not just measure it in its mean effectiveness against the enemy but we must consider our own manpower implications as well.

The handling of stores in a depot is a most complicated business. If you do away with pallet you increase the number of labourers. The case of handling articles on time has to be gone into very carefully before deciding to do away with such things as palletized stores. And lastly, from the soldier's point of view, it is most interesting to see broad principles evolved from experience and training and set down clearly and effectively on paper and analyses. I like Dr. Rumbaugh's presentation of the problems of the air arm in carrying out effective interdiction and it seems to me to be a very good argument for a commander of ground field forces having something to say about how it should be employed."

Col. Parker: "I am not informed about the situation in Western Europe but I would like to comment about that in Korea. I guess what I really want to do is to shed a tear for a principle lost and an opportunity missed. It would seem as though the air force, in learning how to penetrate sound barriers had forgotten how to create them. The principle that has been lost is that in any interdiction effort one should look for a tactical or geographical base line for attacking the parallel routes which serve the forward areas, and select that line so as to get maximum return for effort. Generally, these lines are geographic lines which serve to reduce the number of parallel routes to a minimum and generally, at the same time, to make them more vulnerable.

In Korea, there were two such lines. It was a peninsular campaign, so the lines were relatively short. One of the lines was that of the Yalu and Atumin rivers, across which there was a total of 14 bridges, so bridges were

the targets there. Those were rail and road bridges. Initially, all the supplies brought into the NK and CCF forces in Korea came across that number of bridges on that base line. Now, those bridges were never attacked, and perhaps the principle was lost there because of high level political decisions. However, those targets were extremely vulnerable and to have to forego attack on them was stultifying in a military sense.

There was, however, a second line which was virtually as good as the Yalu river, and that was the line across the upper waist of the peninsular, generally along the line of the Chung Chak river. There again, the targets would have been bridges and defiles, and they were not attacked consistently. No concentrated effort was ever made to intercept all the parallel routes at that line, and there about 75% of all the goods moved forward were being moved by rail, so vulnerability was high. I am very pessimistic, because if we could not wage a successful interdiction campaign in Korea, I don't know how we could do it in Western Europe."

General Marshall: "I rise to my feet for the first time in defence of the Air Force. I would like to say that in Korea, the enemy did find ways of defeating consistent and persistent attempts to interdict at bridges and by the bombing out of rail lines. They developed techniques which were successful. The construction of removable spans which could be wheeled out at night and put into what seemed to be a bombed out bridge and then the removal of that span before daylight was one such device. And with their rail systems, it was a matter of dumping materials every 100 yards or so, including rails, ties, spikes, ballast, and keeping workmen accessible to these spots, so that as rapidly as the line would go off there would be repair men at the spot. I don't think that the interdiction failed because of the Air Force's failure to note those lines, but rather because the enemy found what General Ridgeway called palliatives, and we might as well recognise that that is true.

One of the things which bothered me in the earlier talks was the tendency to stick to the figures quoted as if they are firm figures and must apply to any war in the future. Many of our figures are subject to serious question for many reasons. During World War II and the Korean effort, we worked on an economy of luxury and the figures obtained do not represent efficient figures.

Let's look at these figures. For a division, 500 tons a day has been quoted. In the first place, that is high, according to our data. In the last war, it was, I think, from 320 to 370 tons per day per division, depending on the efficiency of the Corps or Divisional commander. Our overall tonnage was something like 31 million tons in the Theatre, and yet when the war was over we had something like 9 million tons of surplus. In other words, a million more tons than it took to fight World War I. This was due in part to an excessively inefficient accounting system - the inability to say where goods were at any particular time. Now I am just suggesting that it is possible to make a better estimate of the minimum operating needs of a division than anything we have to date. I am perfectly sure that in the form that war may take in the future we are going to find a larger necessary load than we have had before. We cannot think of a war in which we settle down to entrenchments or in which we employ deep shelters for the safety of troops against atomic attack without thinking of an entirely different tonnage figure from what we have known in the past because, as we should have learned from our World War I experience, the moment we get down to the necessity for deep shelters we run into an incredible amount of tonnage. I think you will find that histroy confirms that there has never been a case in which armies were able to settle down to a system of entrenchments without timber, props, etc., running their tonnage figures up to such a point that they had to be based primarily on railroads.

This happened finally in Korea. To a large extent, it was a motorised war in the first year, but in the last two years it was a war based on the railroads, because there was no other way to get the great amount of supply that was necessary forward. I think one of the most interesting, and depressing, aspects of the Korean war, looking at it from the standpoint of our installations, was that the works themselves, and I'm talking particularly

about the splinter-proof works which should have been splinter-proof works in support of the front line, were so extraordinarily heavy. Timbers that were 16" x 16", for example, were quite normal in regimental and battalion CPs. These things were built to last 200 years.

We talk now about the next war being a highly mobile form of war. We say that it has to be different, more elusive, because of atomic attack. And at the same time we talk about the next war requiring us to use earth cover more thoroughly than we have in the past if troops are to survive. We might as well recognise that we are talking about two mutually exclusive propositions."

Col. Tredinnick: "It has occurred to me that in addition to the long range or theoretical discussion of this problem of the L of C, there are several very current and urgent problems that exist. For example, because of the situation we find ourselves in Western Europe, it has been suggested that different types of items should be brought together in each storage area rather than separate storage areas should be built up, each for a single item. This suggests to me the problem of training of individuals skilled in the overall problem of logistics towards supply handling, as we have in our service the trained ammunition handler, the trained quartermaster food handler the trained signals man.

Thus, in studying this problem of assembling different items, we likewise have the manpower problem of training people who can handle these things. Joining to that there is the very current and urgent problem of the organisation of headquarters. From the military viewpoint, this is very important. How is the army or army group commander to organise his headquarters in order to manage this enormous L of C. Are his key people to be right with him, or can they be sent right back to a point in the rear. In a study of World War II organisation, it becomes apparent that no one individual knew where any item of equipment was, and this, of course, led to an enormous over-reach. It seems to me that management controls could come up with a better solution for this very critical problem of the organisation of headquarters, not only for the supplies themselves but also for the information about the supplies.

We have a NATO organisation for utilisation of armies. We don't have to think very far into the future before we begin to wonder what happens if, through the requirements of tactics or strategy, we must exchange armies from one field to another. What happens when you cross your lines of supply? Can they, in fact, be crossed at all?

On the interdiction side, we have spoken mainly of air attacks. There is also the possibility of guerilla attacks against the L of C and we should study how such attacks should be planned to effect the maximum damage."

Brig. Mizen: "My question concerns mechanical handling. In the last war we overcame all the difficulties of the L of C, as far as POL was concerned, by pipeline. This was a really great advance, and we had a smooth flow through the main artery, which makes such a difference. It is obvious that many of the difficulties we have in getting the maximum out of the L of C could be overcome if we could apply the same principle to other commodities."

Dr. Wansborough Jones: "Would the answer to that one be given really by the figures we were given earlier, that is 60% of supplies are ammunition, 30% are POL and 10% other items. Once you have carried your POL forward, the main effort is required on the ammunition. I have no doubt at all that in the pictures that Macklen painted to us of a defile in the middle of an FMA, there is a lot of room for devices such as pipelines which could certainly be developed for such things as small arms ammunition - a fairly easy technical problem I would say. When you have a long run of the sort of length one has with a POL pipeline, I don't think it's going to be an economic job - you will have to use a great amount of steel to begin with."

Mr. Gadsby: "In the general problem of the optimum utilisation and optimum interdiction of the L of C, an important factor is the relative vulnerability of the components of the system.

At AORG we are in the early stages of a study of this problem for the components of the L of C from UK to Northern Army Group. We have tried to work out the proportion of the average daily requirements of different items knocked out per 1,000 tons of HE delivered as bombs. Considering first, general stores, we find that in the FMA 0.7 of the day's requirements are destroyed. In the BOD the figure is 1.5; for ports between 2 and 2.5 and for ships in convoy at sea 8. For POL the figures are: tankers 6; FMA and ports about 9; BOD about 12. For ammunition at a specialised port the figure is 10 to 12 days' supplies; in BOD 0.3; in FMA about 1; and for ammunition ships at sea about 6.

These figures, which apply to an actual force of the order of 7 divisions, are crude at the moment, and corrections for various factors will have to be applied.

You will notice that the road and rail systems do not appear on the list, and this is because these figures are far too low. We found on looking into one or two of these systems that there was such a complex network that we had other far more worthwhile targets.

We feel that the rather obvious solution to the problem is flexibility at every stage. For example, the current practice in this country at the moment is to deliver goods from a factory or ordnance depot to a storage depot, and from the storage depot to the port. We feel that we could get better flexibility by delivery direct from factory to port. There is a tendency, again, to use specialised ports. Thus one port on the Continent might be earmarked for the handling of, shall we say, ammunition or POL. Such a system is, we feel, far too rigid."

Dr. Rumbaugh: "There is one thing I would like to say about inshore areas and about ports. We talk about the atomic threat to them, and forget that there are other threats which are perhaps greater. Of course, they are all functions of geography. In the naval and air campaigns against Japan during Operation "Starvation" towards the close of the war, the closure that was gotten by ground and influence mines applied to the Straights and the Inland Sea, probably exceeded in effectiveness any atomic attacks that could have been carried out on the ports, because they had the effect of denying all the inshore waters, major and minor ports combined. When we think of the European coast, we should not forget the fact that a carefully planned sea mining campaign against ports could be equally or even more effective. I think we are getting a little too atom minded at times and we should remember that other weapons are still very important and that there are targets which are much better suited to conventional weapons than to atomic weapons."

Dr. Page: "Might I make a remark about this last comment. It seems to me that one major factor, namely the time factor, is ignored. Surely it makes some difference whether the effort is made suddenly and in a short space of time or whether it is spread out over a long period of time. In the sea mining mentioned, it was quite important to get the mining done rather quickly, and I think this is supported by the British experience early in the war. A slowly starting mining campaign just does not work because you build up convoys to match the effort."

Mr. Ross: "Dr. Rumbaugh, in his talk, started off with a large problem and broke it down into smaller ones which he looked at. It seems to me that in doing this, one runs into the danger of assuming linearity in the system. I was very impressed by a paper that came from ORO and was presented to your Operational Research Society, called "Optimisation of Sub-programmes" (or, perhaps, "Sub-optimisation of programmes"). In this paper it was very rightly pointed out that when you are concerned with a large problem and you break it down, you have got to make sure that there is no interaction between the small problems and the large one. Now, I feel that we have been neglecting this completely. We have looked at various small points about vulnerability and we have decided that they are vulnerable and that we should do something about it. Now this is not the real problem of operational research. What we must do is

to apportion the effort available between these various things on the basis of an overall assessment. The only thing which is limited is the available effort. This applies to vulnerability of supply lines, to interdiction and to all the problems."

The Chairman asked if any of the main speakers had any further points.

Mr. Kaye: "I would just like to add something to what Mr. Ross has just said. It seems to me that the case of proportioning effort is one which depends critically on Intelligence. You tend to get all sorts of costs analyses of your best returns for the effort you put in, but fundamentally it's all dependent on the accuracy of the intelligence which you are applying that information to."

Maj. Maskell: "There are just two points I should like to make. The first is that I think we must be clear in our minds why we are interdicting. I think there are many targets in which the pay-off is not to be measured in terms of dollars. It is measured in terms of benefit to the tactical effort. I think that is why we feel so depressed when we judge the situation in Korea in terms of dollars when we should be looking at it in terms of the effect on the tactical effort. The failing there was not in what the interdiction didn't do to help the tactical effort, the failure was that there was no tactical effort because it was stopped for political reasons. I think if you look at the situation in Normandy before the landing, you will find that the interdiction scheme was set up as much for deceptive purposes as it was for the destruction of material in terms of dollars. I do think that the value of interdiction must be related to the tactical objects that you are concerned with.

The other point which I think has not had sufficient stress is that of concealing your L of C or of giving them some sort of protection or cover. We did do this very successfully in the last war and I can quote very briefly an example of this, and this was the large scale smoke screen which was used particularly towards the end of the war. The classic case was, I think, the 20 - mile smoke screen which was placed along the Rhine during Operation "Veritable". It took about 1,300 men to maintain and it lasted about six weeks. The interesting point was that it was successful."

Mr. Mound: "As a summary to the ideas I was trying to express before I would just stress the point that in warfare you have limited resources. One resource in which we are seriously limited is manpower. We have producers and consumers; in this case, our producers are back in this country, and the consumers are the soldiers in the front line. We now have a large and ever-growing number of people who are simply passing the goods along. These are the people we must try to get rid of - putting them either at the back or at the front. Hence my emphasis on the desirability of streamlining the supply system."

The Chairman closed the discussion saying:

"I have little to say except that I have been extremely interested in this discussion.

One point I would just like to make is based on listening to predominantly military discussions on just this same point. The first question that the soldiers so often ask is "Is our basic administrative system the correct one? Ought that to be fundamentally overhauled." It has interested me today to find that none of the scientific workers that have been tackling this problem have actually addressed themselves first of all to those two questions. The reason I think is that the whole problem is made up of a large number of parts which should be thoroughly analysed first of all in order to find out what is really the rate controlling the process. It does not surprise me at all to find in practice that the basic administrative system which is the product of a national growth of two or three hundred years of experience is apparently accepted tacitly as the correct one.

Thank you, gentlemen, very much indeed for your very interesting and valuable discussion."

FINAL PAPERS

The last day of the conference was devoted to the presentation of three formal papers designed to give a wider audience some idea of particular items of operational research being carried out by the countries represented.

The meeting was opened by General Sir Ouvry Roberts, Quarter-Master-General who welcomed the delegates.

"Gentlemen, I should like first of all, on behalf of everyone in the Army, to welcome you here. I must say I am tremendously impressed by the numbers who have come from the U.S.A. and from Canada to this country, and I like to think they have come because they find the discussions of value and not merely, as suggested to me just now by one of your eminent members, that it is a nice holiday in Europe. But there can be no doubt whatsoever that, coming in the numbers you do, you appreciate the value of tripartite organisation and discussion.

I shall be grateful if you will express to Dr. Ellis Johnston our regrets that he is unable to be here. I understand he is in Korea at the moment doing a job there. I'd like to welcome you, Dr. Rumbaugh, and all your delegation, and to thank you very much for coming in such strength. General Marshall, whose name is well known to us all, is here too, and I hope I shall meet him in the course of the morning.

Then from Canada, there are Mr. Kaye, Col. Boehm, Col. Carrie and Dr. Morton amongst others. You too, from a very small organisation have come in very considerable numbers, and that is a great spur and incentive to us. Dr. Morton has, I understand, attended every one of these tripartite discussions that has taken place, and I hope he will attend many more. I think that is sufficient proof that you understand the value of this tripartite discussion, and it is not necessary for me to labour the point, except to say that we, the soldiers, appreciate it very much indeed, and we are sure that the exchange of staff which we have proves of enormous value.

In spite of what we read in the papers, both on the other side of the Atlantic and on this side, I am convinced that the three of us are daily and weekly and yearly growing closer and closer together. Differences arise of course, but what I think is encouraging is the way in which these differences are always, in the end, ironed out and I am quite sure that the alliance of the English speaking peoples is, at the moment, the only sure way to peace.

I have had a look through the matters which you have been discussing. Now I am Quarter-Master-General, and as such I am concerned with logistics. It is more and more evident that, with our increasingly intricate and increasingly technical forces, logistics are playing an increasingly important part. There are three items, in the eleven which you have discussed, on logistics but it is not so much the number of items as the amount of time spent in discussion which is important. I don't know what the time was, but I do want to emphasise that I think there is a great deal of essential study to be done in this field. Somehow we have got to make it possible to get our supplies forward without increasing our manpower and at the same time we have to reduce our vulnerability and our dependence on fixed points. Well, that is what I expect you to do for me. Undoubtedly one direction in which we must look is that of air transport.

I would like to end by repeating my thanks and by expressing my appreciation of the value we find in this research organisation in this country and in the corresponding organisations in America and Canada. The soldier does, nowadays, appreciate the importance of the scientist to him. There is one point I would like to leave you with on this: I don't believe that we quite get together enough throughout our study of our problems. I may be wrong in this but I feel that the scientist does not yet come to us freely enough and say "Look here, you're being foolish, you're doing the wrong thing. Why don't you do so and so?" Well, we want that, and if there is any hesitation on our part, I hope you will come back again and again because, as I see it now, the biggest problem that lies before us, and the one that you

and many others have to solve, is how on earth are we going to produce defence forces capable of doing their job within the limits, not so much of finance, as of productive capacity. We are going now to the production of everything from the atomic bomb through guided weapons down to highly complicated radar and electronic instruments, and this calls for an enormous effort of technical skill, and there is not enough in this country, or even in America probably, to meet all the demands. Somehow, we must cut those demands down and it is here that the scientist must tell us how we can get a reasonable solution with a reasonably economic use of money, materials and skill. Thank you."

THE INFANTRY RIFLE - OPERATIONAL EMPLOYMENT AND SUGGESTIONS FOR A NEW DESIGN

(Presented by Col. E. M. Parker)

For some time now the Operations Research Office has been studying the infantry rifle. The purpose of the undertaking has been to develop a logical relationship between the actual function and the design of the weapon, and to discover whether it might be possible to increase the number of hits obtained per pound carried by the individual infantryman.

The study was conceived in the first instance by Mr. Norman Hitchman. The basic experimentation was designed and conducted - with Army participation and assistance - by Mr. Hitchman and others of us, including Lieutenant Colonel D. E. Munson, who is assigned to ORO as a military adviser. Statistical analyses were made by Mr. Scott Forbush. Colonel Munson is attending this conference as a member of the US delegation; but neither Mr. Hitchman nor Mr. Forbush is present.

Supplementing our own experimentation, data from a number of other inquiries have entered into the general evaluation. We have used, and credit is therefore due, the work of many outside ORO. Included in the over-all synthesis is original work done by Mr. David Bayly Pike while posted to ORO as the liaison representative of AORG.

I can speak but weakly, then, for all these others, the principal workers.

The first phase of this continuing study culminated about six months ago when the findings to that date were released. Publication took the form of a Technical Memorandum carrying the title "Operational Requirements for an Infantry Hand (that is, "shoulder") Weapon". The document has been distributed through the usual channels, to include the UK and Canada.

This study of the rifle was undertaken not only because of the very real importance in combat of rifle fire, but also because of certain observed deficiencies in such fire as at present developed and applied - and as, apparently, it is proposed to develop and apply it in the near future.

The concern here is with "aimed" rifle fire. Actually, it would not be inappropriate to call this "aimless" rifle fire, since errors in aiming are so general and so large, and since the inherent capabilities of the weapon are in practice so incompletely realised. Indeed, the situation is so bad that hit probability for "aimed" fire is found to be very little if at all greater than for small arms fire which is intentionally and altogether unaimed. However, the point to be made is that this analysis has been focused upon the performance of combat riflemen, in directing bullet missiles at separated man-targets, which are seen within range. The contrast is with neutralizing, covering, and other - principally assault - fires, which account for slightly more than half of total rifle ammunition expenditure, and which have a definite tactical utility, but which do not necessarily often involve the individual direction of fire at point targets. All of the argument which will be adduced applies to this so-called "aimed" fire, whereas some small part of what will be said may not apply (as will be obvious) to those few fires of the covering type which are legitimately unaimed.

Importance of Aimed Small Arms Fire

Despite the very important roles of the support weapons (artillery, armor, tactical aviation, mines, and others), and despite their predominant part in inflicting casualties as averaged over all tactical situations, the entire ground fire system hinges both tactically and physically upon the infantry weapons. And among these infantry weapons the rifle is of special value, for it offers certain capabilities not duplicated - nor, in many common situations,

Note: The speaker stressed that the points presented in this paper were not to be taken as representing the official policy of the United States.

even supplemented - by any other means. For example, Korean operations have emphasized that often the defence of a position depends more upon fire from the rifle (and carbine) than anything else, and that it is such fire that ultimately decides the issue. S. L. A. Marshall writes of Korea:

> "Infantry must depend in the main on the self-sufficiency of its own weapons.. and rifle fire... (often)... becomes the chief preservative of the force as a whole... even when artillery has many targets".

Indeed, whenever and wherever faced by a numerically superior enemy, one must anticipate frequent attempts to overrun his forward positions, with attendant close combat and the loss of all supporting fires. Moreover, as a [1] quite independent consideration, situations not uncommonly arise in which poor visibility, disruption of communications, or even just general confusion, close out all supporting fires - even those of the infantry heavy weapons.

In modern combat - as, indeed, in most wars of the past century - bullet hits from small arms have accounted for about 20% of the total hits. About 30% of these bullet hits are lethal - which amounts to a higher lethal index for small arms than for any other weapons yet used in combat.[2] Until extensive and painstaking surveys have been made, it will not be possible to say exactly what fractions of all these bullet hits and these bullet kills are to be attributed to "aimed" rifle fire, but the fraction is certainly substantial.[3]

Thus, we consider the basic weapon of the basic branch: the rifle carried by the infantry. It is a truly indispensable weapon, not likely to be eclipsed - in any type of ground combat reasonably to be expected - by any other weapon, new or old. Even in an atomic age, the rifleman retains his basic importance.

Aside from such considerations of the vital tactical function of the rifle, any examination of the weapon at this moment is timely because the NATO is confronted, now, by an urgent requirement for the standardization of a general purpose infantry shoulder weapons. Even though the US position has already been unequivocally (if somewhat arbitrarily) stated, and even though a measure of joint agreement has been wrung from the NATO standing group, any information bearing upon the operational effectiveness of different designs may have a useful application to an immediate problem of some moment.

Deficiencies in Rifle Fire

Certain deficiencies in rifle fire, tending materially to detract from both the effectiveness and the efficiency with which the vital role of the rifle is carried out, have been noted.

Antecedent ORO studies have disclosed that the regional distribution of wounds from bullet hits in combat is the same as for fragment missiles, and that exposure is the factor chiefly responsible for the distribution, according to body region, of bullet hits. Thus the fact emerges that the rifle bullet is not better directed toward vulnerable parts of the body, despite the high intrinsic accuracy of the rifle proper, than the fragments from mortar and artillery shells which fly completely at random so far as individual man-targets are concerned. Yet that important characteristic of rifle fire called "stopping power" (about which many misconceptions exist[4]) is largely dependent upon the particular body region hit, and is thus - as distinguished from "wounding power" - far less a function of terminal ballistics than of weapon accuracy and aiming. Since average performance in aiming is so poor, hitting a point which is critical from the standpoint of "stopping" the target is necessarily quite fortuitous.

A second point is that the (total) combat expenditure of small arms ammunition per hit is prodigious - some 8,000 to 12,000 rounds. What statistical data are thus far available from US experience do not clearly show the rifle either more or less efficient, round per round, than the Browning automatic rifle and the machine guns proper,[5] and so it is unlikely that

riflemen obtain more than one hit per 10,000 rounds of ammunition issued. This is "aimless" fire with a vengeance.

There thus arises an exigent requirement for increasing the number of hits obtained.

It is also - probably - desirable to increase the severity of those hits. Setting a limit to the possible gains from any such increase, however, is a consideration just noted: namely, that almost no amount of mechanical energy or momentum which may be attained in a bullet type missile will suffice to cause an immediate incapacitation if the hit occurs anywhere but at or close to a vulnerable spot; whereas, hitting a man in such a vulnerable spot with a bullet possessing any amount of energy above a very small threshold value (about 60 ft.-lb.) will "stop" or stun him. Thus it appears very difficult to increase "stopping power" by any mechanical modification of the weapon affecting only terminal ballistics, simply because the accuracy of the man-rifle combination cannot be improved to such an extent as to increase the proportion of strikes on vulnerable portions of the body (except for those hits obtained by snipers).

This is not to say, however, that "wounding power", in general (as distinct from immediate incapacitation) may not be materially improved[7]. Moreover, it may be noted that any improvement in "wounding power" which includes a substantial increase in the area of involvement will tend to give at least some small increase to the expectation of "stopping" a target, just because the effects of a hit near a critical point, that is of a reasonably near miss, may extend to that point.

Again, though only the specialist of high aptitude and extra training (that is, the sniper), can be counted upon actually to obtain some hits at selected points in the exposed body area, an approach to systematic area coverage (such as practiced by artillery) should permit the average riflemen to score many more hits at random locations in that total exposed body area than he now does. Surely, some increase in both single and multiple hit probability, over that reflected in the grossly inefficient figure of 10,000 rounds per hit, should be not only possible but feasible.

Consideration Prompting the Study

Such are the considerations which prompted the study under discussion - and which one hopes will likewise prompt careful consideration of the findings. We believe that the analysis yields suggestions as to how operational effectiveness may be improved, at a saving rather than any increase in overall logistic cost. Both terms in the effectiveness - cost ratio figure may be made more favourable.

THE INQUIRY

Operational Data

Let us then examine the operational employment of the rifle, and see whether the design characteristics of the weapon, on the one hand, and the observed performance of the man-rifle combination, on the other, are consistent, and whether they are together logically related to the actual requirements and established use patterns for combat rifle fire.

A group of functionally related characteristics is of interest, namely:

1. Range;

2. Hit probability (hits per pound of ammunition and associated weights);

3. Rate of fire

4. Wounding power; and

5. Caliber and muzzle velocity (as reflected in: weight of rifle and ammunition; recoil).

There are other characteristics, such as balance, adaptability to the bayonet and grenade launcher, ease of field maintenance, reliability and durability which are of military importance; but none of these is operationally dependent upon any of the five related characteristics just named, and none presents a difficult problem nor a seriously inconsistent design requirement. One omits nothing relevant, therefore, in concentrating in an operational analysis, upon range, hit probability, rate of fire, wounding power and caliber.

In considering these characteristics, the design and performance of the current US standard rifle, .30 caliber semi-automatic called the M1, will be used as reference points. The British .303 is generally similar, save that muzzle velocity and energy are somewhat less.

RANGE OF EMPLOYMENT

Design Characteristics

This current M1 rifle with its standard ammunition has an extreme range of 3,500 yards. Bullets from this weapon can cause a "fatal" wound through normal military clothing and web equipment at 2,000 yards, and will penetrate the helmet or light body armor and inflict "severe" wounds at 1,200 yards. The weapon has a muzzle energy of 2,800 ft-lb. The military characteristics, which are specifications of performance, currently specified by the US Chief of Army Field Forces (and by the NATO Standing Group with respect to ammunition only) restate these capabilities for the new US (or the NATO) light-weight rifle, save that extreme range is not specified. Both the current US experimental models, the T44 and T47, using the T65 (or T93 El) ammunition, possess these design characteristics (except that a somewhat lighter bullet causes the muzzle energy to fall).

(Somewhat in contrast is actual training doctrine in the US, as set forth in our Field Manual 23-5 which states that the effective combat range of the M1 is 500 yards, and that the battle sight shall be zeroed at 300 yards).

Actual Range of Employment

Quite inconsistent with these prescribed design capabilities are the following operational data:

1. Surveys by AORG have developed that, in World War II, 80% of all effective rifle fire was delivered at 200 yards or less, and only 10% was delivered at ranges exceeding 300 yards. (AORG Liaison letter, Dec 1951).

2. Donovan, in an ORO technical memorandum, reports upon a survey, of 636 EM, averaging seven months of Korean service. It was found that:

    a. 85% of daytime offensive fire was at less than 300 yards.

    b. 80% of daytime defensive fire was short of 300 yards. (ORO-T-18 (FEC): Use of Infantry Weapons and Equipment in Korea) June, 51).

3. Kaye, in a joint US-Canadian report based on examination of officers and non-commissioned officers of the 2d, 3d, and 45th US divisions, with eight months or more of Korean service, confirms the Donovan findings. (ORS/Korea Report No. 6: Use of Infantry Weapons in Korea - to Mar. 52).

4. S. L. A. Marshall in an ORO publication writes: "Effective rifle fire ... (in Korea)... was consistently at less than 200 yards". And again: "In no case... was effective rifle or carbine fire delivered at a range in excess of 200 yards". (ORO-R-8(13)(EUSAK): Infantry Weapons Usage, winter 50-51).

All these data refer to our own use of the rifle. What little we know of

enemy practice is also of interest:-

5. Oughterson reports that in the - admittedly special - circumstances of the Bougainville campaign, 80% of the rifle bullet wounds incurred by our own troops were received at ranges less than 75 yards. (Wound Ballistics Report, Bougainville Campaign Col. A. W. Oughterson).

6. A team from the Medical Research and Development Board of the Office of the Surgeon General examined about 400 of the Turkish Brigade who were wounded in Korea in late November, 1950. It was found that 71% of all bullet wounds had probably been received at less than 300 yards. (Wound Ballistics Survey, Korea, 15 Nov 50 - 5 May 51).

Finally, so far as range is concerned, it has been determined at ORO than an upper limit is set for the rifle as a direct fire weapon by obstructions to visibility which are associated with battlefield terrain.

7. Bayly Pike, in an ORO technical memorandum, reports on some interesting and highly relevant findings with respect of the distances at which a prone infantryman can see an erect man target. The findings are summarized in Figure 1. It will be noted that: Only 30% of the time can the prone infantryman see an erect man target -

   a. Beyond 165 yards, in Korean terrain

   b. Beyond 320 yards, in terrain of which the Normandy battlefields are typical

   c. Farther than 600 yards, in very flat terrain such as that of Ontario.

   As an over-all average of some 19,000 field and map readings, it is found that the rifleman can see a man target beyond 300 yards only 30% of the time; 70% of the time he cannot. (The median range is 175 yards). (ORO-T-161)

These limitations to aimed fire, occurring even in the daytime during good weather are corroborated by

8. S. L. A. Marshall, who observes in connection with visibility and the November - December 1950 operations of the US 24th Division in Korea: "The distance for recognition of rifle targets in daylight was 50 - 200 yds". (ORO-T-7 (EUSAK)).

These findings as to range are all in good general agreement. For Korea, they are summarized in Figure 2. As might be expected, the frequency of fire slightly exceeds that of seen targets in general; and ranges tend to be a little greater in the defence than the offence, which is normal. However, the correspondence is good: the distribution is similar and the frequency values are not very different except for those ranges at which unaimed covering, marching or other similar assault fires are commonly delivered.

Conclusions

From these data one concludes, directly, that the <u>ranges at which the rifle is used most frequently, and the ranges within which the greater part of the man targets can be seen on the battlefield, are alike less than 300 yards.</u> Quantitatively, all the evidence shows the frequency of occurrence of the lesser ranges to be about 75% of the time. Consequently, there is a prima facie indication that certain more or less costly design provisions for greater ranges may be relaxed (even though not entirely discarded, since a range or distribution of effect which does not exclude greater ranges is, of course, required). <u>The efficiency, then, of the general issue rifle may be improved by designing for optimum effect at the common battle ranges.</u>

Marksmanship and Musketry

Weapon Accuracy and Aiming Errors, Semi-Automatic Fire

The operational accuracy of the rifle depends not only on the ballistic qualities of weapon and ammunition, but also - and much more importantly - upon the rifleman's skill in aiming. The total dispersion around the main point of impact (for a Gaussian distribution, such as obtains in rifle fire) may be calculated as the root mean square of the two independent errors involved, namely: 1) the dispersion occasioned by faulty aiming; and 2) that arising from weapon-plus-ammunition irregularities. If the degree of precision achieved by the man were commensurate with that mechanically packaged for him in his weapon and ammunition, any appreciable correction of either source of error would meaningfully diminish dispersion at the target. However, if one type of error is large with respect to the other, no reduction in the smaller will be to measurable avail. Actually, the precision now built into weapon-plus-ammunition is grossly inconsistent with performance of the man, and hence with the man-rifle combination. We determined in the course of the range tests made for this study that the probability that the average qualified marksman armed with the M1 will hit a man-size target, in such conditions, at 300 yards, is .25. The probability of hitting with the rifle in a machine rest is .96. To put it the other way about, the miss probabilities are, .75 and .04. (The latter figure corresponds to a mean radial dispersion for the US M1 of approximately 2R inches, where R is the range in hundreds of yards. Curiously enough, this is slightly less than the degree of man-weapon accuracy at present insisted upon). Furthermore, although one does not know exactly how actual combat conditions degrade performances, the reduction in effectiveness as compared with what the soldier does in a manoeuver or on a practice range is certainly very great. Realistic though we tried to make the firing experiments for our study, we could, of course, only simulate some of the pressures of battle.

Thus, the rifleman is disclosed as the weak link in the man-rifle combination - by more than an order of magnitude. Scarcely any amount of training or battle experience can so improve the man as to put him at a level of precision even approaching that of the rifle. Yet, in the US, Board No. 3, at Fort Benning, Georgia, the Office of the Chief of Army Field Forces, and the Ordnance Corps, all agree that any new rifle must be at least as precise as the present M1, and no experimental models are, in fact, of lesser design accuracy.

To obtain data on marksmanship, Hitchman (assisted by Colonel Munson) designed and conducted, with the co-operation of the Engineer Center, a series of field tests at Fort Belvoir, Virginia, in which both marksmen and expert riflemen fired the M1. By requiring fire at unknown ranges, by varying the time and location of target exposure, and by imposing various forms of psychological duress, it was possible to create a more realistic situation than obtains in ordinary firing exercises, the development trials of the producing service, or even the user acceptance tests of agencies such as our Board No. 3.

In these tests, bullets missing the target were caught on large 6-ft x 12-ft screens in order to permit analysis of aiming errors.

It was clearly established in the course of these tests that a generally low order of marksmanship prevails. Performance was poorer than anything expected - even by one aware of the deficiencies in combat rifle fire. Moreover, performance was altogether inconsistent with both the design capability of the present weapon and the military characteristics prescribed for new rifles. (The dispersion of the weapon could be more than doubled without noticeably affecting hit probability at any range).

Conclusions

The results of these Fort Belvoir Tests show that, in semi-automatic fire:

1. Up to only 100 yards is hit probability reasonably good, even for the highest grade of marksman.

2. At ranges beyond 100 yards, hit probability declines sharply, the fall-off being most marked at the common battle ranges, that is up to 300 yards.

3. At 500 yards hit probability is so low as to mean essentially that the rifle (as an aimed fire weapon) has no utility, no tactical value, at any such range (sniping fire always excepted).

The findings are summarized in the curves of Figure 3 and related to both the ORO battle visibility studies and combat experience in Korea. (Here may be seen correspondence between (1) hit probability computed as a product of hit probability for seen targets and the probability of seeing a target both as a function of range (and with ammunition expenditure taken as proportional to the number of targets seen); and (2) the hits actually occurring in an analysed Korean situation. It will be remarked that the correspondence is good and hence that, for the example at least, the methodology appears sound.

Full Automatic Fire

Full automatic fire at a cyclic rate of about 400 rounds per minute 10/ is a prescribed military characteristics for any new US rifle. It is further prescribed that for 2-3 round bursts, with muzzle or elbow rest, all shots at 200 yards shall fall in a 24" circle; and that for 5 round bursts from the standing position all shots shall fall in a 24" circle at 50 yards. (As of Jan 52 it was 80% of shots in 30" circle).

At Fort Benning, the Infantry School and the home of Board No. 3, ORO arranged full automatic tests with the present standard, and the new or experimental rifles, which incorporate the full automatic feature. Type E silhouette targets (which are silhouettes of a kneeling man) were mounted in front of 6-ft x 6-ft screens. Riflemen qualified as experts used the prone position and were allowed to "zero in" at leisure.

In 5 round bursts at 100 yards, not once was more than a single hit scored on target or screen. Not until the range was closed to 50 yards was more than one strike obtained on the screen, and even then there was no multiple hitting of the target. (Since single shot firing at this range with the M1 yields at hit probability that is virtually unity, the effectiveness of automatic fire at such short ranges was of no interest).

It is interesting to note the corroboration which comes from the thorough joint trials of the British EM-2 and the FN rifles, and the experimental US T25, conducted by Board No. 3 in 1950. At that time, in matching performance against the full automatic fire accuracy mentioned earlier, it was found that the accuracy demanded at 200 yards (24" circle, using rests) could not be obtained for a single 2-3 round burst with any rifle beyond 50 yards, and also that the accuracy set for 50 yards (24" circle from the standing position) could be obtained from the prone position only, 11/ and then for not more than 25% of the time.

Conclusions

It is concluded that, in full automatic fire:

1. At normal battle ranges, regardless of the skill of the rifleman, all shots after the first in a short burst fall off a man-size target in an approximately linear pattern, the progressively greater departures depending in magnitude and direction upon the characteristics of the weapon and the manner in which held. 12/ It may be said that the automatic fire hit probability for separated targets does not for any weapon yet tested exceed the single shot probability in (slow or) semi-automatic fire.

2. The dispersion is so great that placing the center of impact for a burst on the center of the target would not increase the number of hits.

3. The full automatic feature of both current and proposed rifles is

valueless from the standpoint of increasing either the number or rate of hits on separate man targets.

Compensating for Aiming Errors

Despite these discouraging inaccuracies, there appears a possibility of increasing the ability of the rifleman to hit his target.

A statistical analysis of bullet strikesin the Belvoir tests, as made by Forbush and Blakemore of ORO, has suggested an alternative to the clearly very rare degree of aptitude, coupled with extensive training, which would be required to produce rifleman truly proficient in combat. It seems not only possible, but feasible, to compensate largely for man aiming errors through incorporation in weapon design of a pattern dispersion principle. Although not all possibilities have been investigated, analysis suggested that a cyclic or a "salvo" automatic projecting shots in a controlled (or even random) dispersion pattern, might be one means by which hit probability (per trigger pull or burst) could be greatly improved. A weapon designed to project such a pattern simultaneously (or at a high cyclic rate) would not only increase hit probability at the ranges of greatest interest, but would also do so out to such extreme battle ranges as 500-600 yards.13/ (See Figure 4).

In making this suggestion as to controlled dispersion, ORO does not yet speak with full information on engineering feasibility, but merely describes the principle of a desirable design feature. Actually, the staff at Aberdeen Proving Ground14/ in the US and other expert advisers, supported now by some investigations of our own, affirm that there appear to be no major technological obstacles to the production of a rifle which could provide a certain dispersion pattern through controlled mutation of the muzzle with a set length of burst, in a cyclic weapon; or through a fragmenting bullet, a series type load, or a shot gun type of projection, in a true "salvo" automatic.

Conclusion

One concludes, then, that although aiming errors are so great that neither maintained or increased ballistic accuracy in a new rifle can contribute to improving hit effectiveness, nevertheless:

> Projection of a dispersion pattern designed to maximize hit probability at the most frequent ranges might largely compensate for the aiming errors which reduce the hit probability of present standard and experimental weapons to such a very low level.

Wounding Power, Caliber and Muzzle Energy

Another tactically (and, of course, quite obviously) important characteristic of a military rifle is its capability of causing incapacitation as a result of a hit. In the US, the headquarters and agencies charged with weapons development have long been adamant in saying that no rifle with a muzzle energy less than about 2800-ft-lb, nor a caliber less than .30,15/ will ever be militarily acceptable. It is not really believed that any bullet of a caliber smaller than .30 will be satisfactory in wounding power; nor, as one official indorsement put it, sufficiently impressive to the enemy "when heard passing overhead". However, such attitudes and such statements are open to attack. The arguments for a small caliber high velocity military rifle are cogent, especially in connection with a design affording controlled dispersion.

Terminal ballistics, rather than strike energy alone, determine wounding power (for any given body region). What is critical is the transfer of energy from the bullet to the tissue or bone. The severity of a wound depends - presuming a certain minimum of available energy - upon the efficiency and speed with which the kinetic energy of the bullet is absorbed by the target. A .30 caliber bullet of a large mass, or a hypodermic needle in a steady hand, may burrow through muscle tissue along a beautifully undisturbed trajectory, transmitting little energy and creating only a neatly perforating or penetrating wound of little psysiological consequence. The very ballistic stability of such missiles is against them.

Wound ballisticians now know that wounding effect, of which the volume of the maximum temporary cavity produced by the bullet is the best measure, varies more nearly with the cube of the velocity than the square. In a viscous medium the energy expended, or the work done, varies as the speed with which the deformation is produced.[16] Consequently, although the energy available for causing a wound is a function of the second power of the velocity, the energy transfer and resulting cavitation are related more closely to the third power.[17] The mass of the bullet enters into the equations for momentum, energy and power with an exponent of only unity. Therefore, gains which may be achieved by increasing the velocity outweigh the loss occasioned by a corresponding reduction in bullet weight or caliber.

Cavitation, and especially the very extensive extravasation (that is, the haemorrhaging), are both possibly influenced in another way by missile velocity. The strike velocities which may be readily achieved with small calibers are so high (of the order of 3,500 to 4,500 ft/sec) as to approach the speed of sound - or the speed of transmission of shock waves - in muscle tissue or viscera. It is probable that some of the violent phenomena associated with the motion of a body through a medium of such a speed accompany the strike and penetration of a small caliber high velocity bullet. Certainly bullet strike at very high velocities, such as 6-9,000 ft. per sec, causes extremely violent physiological reactions of a type not yet explained.

Although not all the answers are yet at hand, theory in these areas is advancing, and is supported by a not inconsiderable body of experimental evidence. Sporadic early investigation by the US Army and other agencies has been followed by recent work at the Army Chemical Center; at Princeton University under the direction of the National Research Council; and at the Ballistics Research Laboratory at Aberdeen Proving Ground. Wounding by a range of calibers from .30 to .22, with reasonable powder charges and easily attainable velocities, has been observed in experiments upon goats, dogs, cats and pigs, and in experiments using gelatin and clay tissue models which almost exactly reproduce actual tissue deformations (when experiments are properly controlled). Effects have been measured by serial dissection, direct volumetric readings, by micro-second X-ray photography, by shadowgraph, and by high speed motion pictures. (The performance of small high velocity spherical pellets has also been observed).

Representative of the findings are such determinations as these:-

1. In the late 1920's the so-called "Pig" and "Goat" Boards of the US Army made an extended study of calibers smaller than .30, including a series of firings at live animals with .256, .276[18] and .30 caliber bullets. It was found and officially reported that the .256 was the "worst killer" (that is, from our standpoint, the "best" killer). Any of the calibers would kill or disable up to 1,200 yards. The .276 was almost as effective as the .256, and its adoption was decided upon[19] at every level in the US Army below that of the Chief of Staff, at whose, however, it was disapproved. Since that peremptory rejection, those ideas which have arisen as to calibers smaller than .33 have received scant consideration and no official favor.

2. The Chemical Corps Medical Research Laboratory has recently found that:

   a. A 40 grain, .22 caliber model of the standard caliber .30 M2 bullet is air stable at common ranges, being ballistically superior to the .30 caliber out to at least 500 yards when given a muzzle velocity of 3,500 ft per sec or better.[20]

   b. Temporary cavities become very large at strike velocities exceeding about 2,600 ft per sec.

   c. Pointed bullets, of standard military shape, tumble more readily in tissue,[21] and are therefore mechanically more efficient, at all velocities, in transferring energy to tissue than are round

nosed or "mushrooming" bullets. Smaller calibers, in general, tumble more readily than the .30.

d. Up to 500 yards, the .22 is very much more effective than the .30 caliber in producing large temporary cavities in gelatin tissue models and goat hind leg muscles, and severe trauma in the goat leg. The majority of goat femurs can be broken by .22 caliber bullets, of 3,500 ft per sec velocity or better, passing through muscle without striking bone.[22]

3. Confirming the pioneer work of Burns and Zuckermann in England, Harvey and his associates at Princeton University have found that "the temporary cavities produced in living animal tissues by the passage of high velocity pellets are many times larger than the permanent cavities ordinarily observed". In the language of the report, "the formation of this large temporary cavity brings about a large displacement and tearing of the tissue and gives a reasonable explanation of the abnormally great amount of damage produced by small, high velocity missiles".[23]

4. Hall, of the Ballistics Research Laboratory at Aberdeen Proving Ground examined, both experimentally and by computation, a range of calibers, from .30 down to .22. His findings may be illustrated in one way by the quotation: "In general... at ranges up to 800 yards... if the combined weight of rifle and ammunition is fixed at 15 lb, a rifleman armed with a .22 caliber has the expectation of killing 2.5 times as many man targets as one with the M1". This follows from a flatter trajectory, better energy transfer after strike, as good or better helmet and light armor penetration at ranges up to about 900 yards, and an increase in the number of shots. As illustrative only, and not to be taken as indicating that a particular caliber is necessarily selected by Hall or by ORO as the optimum, certain observed characteristics and effects of a .22 caliber, firing a bullet homologous to the US standard for the M1 rifle, at a muzzle velocity of 3,600 ft per sec, and a muzzle energy of 1,780 ft.lb., should be noted. In Figures 5, 6, 7 and 8 clear superiority of the .22 is demonstrated with respect to:-

a. Cavity volume vs. strike velocity, with the latter reduced to values for .30 caliber.

b. Cavity size vs. range, normal small caliber velocity.

c. Remaining velocities, vs. range.[24]

d. Maximum ordinates to the trajectory vs. range.

Conclusions

With respect to wounding power, caliber, and muzzle energy, it is thus concluded that, at the cost of only small losses in armor penetrating ability at ranges generally beyond those of interest, and in extreme range - both of which are capabilities of scant operational value - a caliber smaller than .30, with a reasonably high muzzle velocity and good ballistic qualities, offers:-

1. Greater wounding power.

2. A generally improved trajectory, with a longer continuous danger zone, and reduction of the effect of errors in windage and in range estimation.

3. Some reduction in energy of recoil.

4. Decreased weight of rifle[25] and ammunition, plus many associated logistics savings.

RECAPITULATION: THE FINDINGS

Limitations

At this point, it will be apparent to all of you that this study is not in every respect complete. As its upshot, one cannot urge in opinionated fashion the letter of any specification as the "approved solution" to the whole problem. Neither can one say, complacently, "here are the data; this is the action indicated; end of problem".

For one thing, our knowledge - everybody's knowledge - of what happens in combat is strictly limited. No one yet knows precisely how the outcome of battle, or the aggregate of combat effort, is influenced by what weapons and what tactical actions. In an operational sense, as you will all appreciate, knowledge of battle is in general imperfect, often no better than fragmentary. We do not know - and there is no one who can tell us - how our observations of the performance of riflemen under simulated combat conditions should be degraded to accord with the actuality.

Moreover, we have made only exploratory excursions outside our own province and into that of development research for to determining engineering and technological details.

Thus, our answers fall short of encompassing an integrated whole, for the reason that our experiments have been limited in size of samples and range of variables; because extrapolation from simulated combat to the real thing is fraught with order of magnitude uncertainties; because we have not yet developed a true "pay-off" function for rifle fire; and because how to engineer all the principles of design which are suggested is a matter not yet fully investigated. We are able to prescribe no neatly final panacea.

But, such considerations notwithstanding, it is no more than proper to emphasize that our findings rest squarely upon experimental evidence. The different sorts of evidence examined are mutually confirmatory to a rather extraordinary degree. Notice the consistency, the logical interdigitation, of the facts bearing upon ranges of employment, of wound incurrence, and of battlefield visibility. Remark the fit of the evidence on full automatic or volume fire; and on small caliber, high velocity missiles. The argument seems straightforward and compelling.

Conclusions

Let me recapitulate, then, in language which does not exaggerate the finality of our analysis, but which does amount to a forthright statement of what we believe to be established:

1. Weapon employment data and battlefield visibility data alike show that in effective fire relatively short ranges of engagement preponderate - not only as a matter of observed practice, but of physical necessity as well. About three-quarters of the time aimed rifle fire is (and can be) delivered only at ranges less than 300 yards. There remains, therefore, only a strictly limited requirement for fire at greater ranges.

2. In the man-rifle combination, aiming errors are generally large - far in excess of purely ballistic dispersion. Thus, (if at any extra cost, and in a general purpose weapon) design provision for the currently prescribed degree of precision is inefficient.

3. A controlled dispersion feature may largely compensate for aiming errors.

4. The full automatic feature does not increase the expectation of hitting separate man targets.

5. A caliber smaller than .30, with a correspondingly increased velocity, offers - at some cost in "armor" penetration: 26/

    a. Greater wounding power

b. Generally improved ballistics at the ranges of interest.[27]

c. Somewhat reduced single shot and cumulative recoil effects.

d. A lighter and shorter round.[28]

e. Some decrease in rifle weight.[28]

These improvements, all of general value, take on a special significance in connection with the controlled dispersion weapon recommended.

Recommendations

And, finally, we have made a single recommendation, which is simply that:-

A small (but adequate) number of prototype weapons, incorporating the features suggested as desirable, be fabricated and tested in order conclusively to determine their military value and engineering feasibility."

BATTLEFIELD VISIBILITY

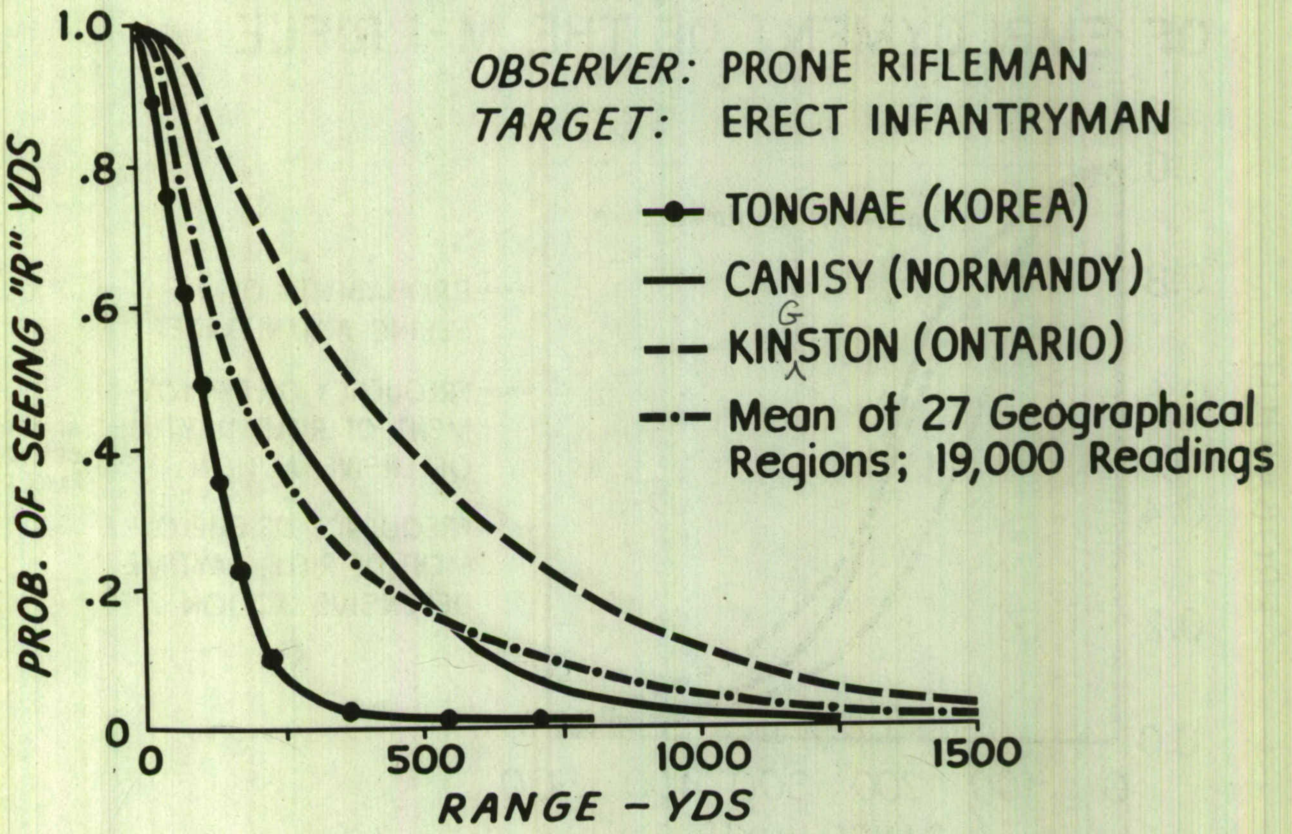

FIGURE 1

BATTLEFIELD VISIBILITY IN KOREA AND RANGES OF EMPLOYMENT OF THE M-1 RIFLE

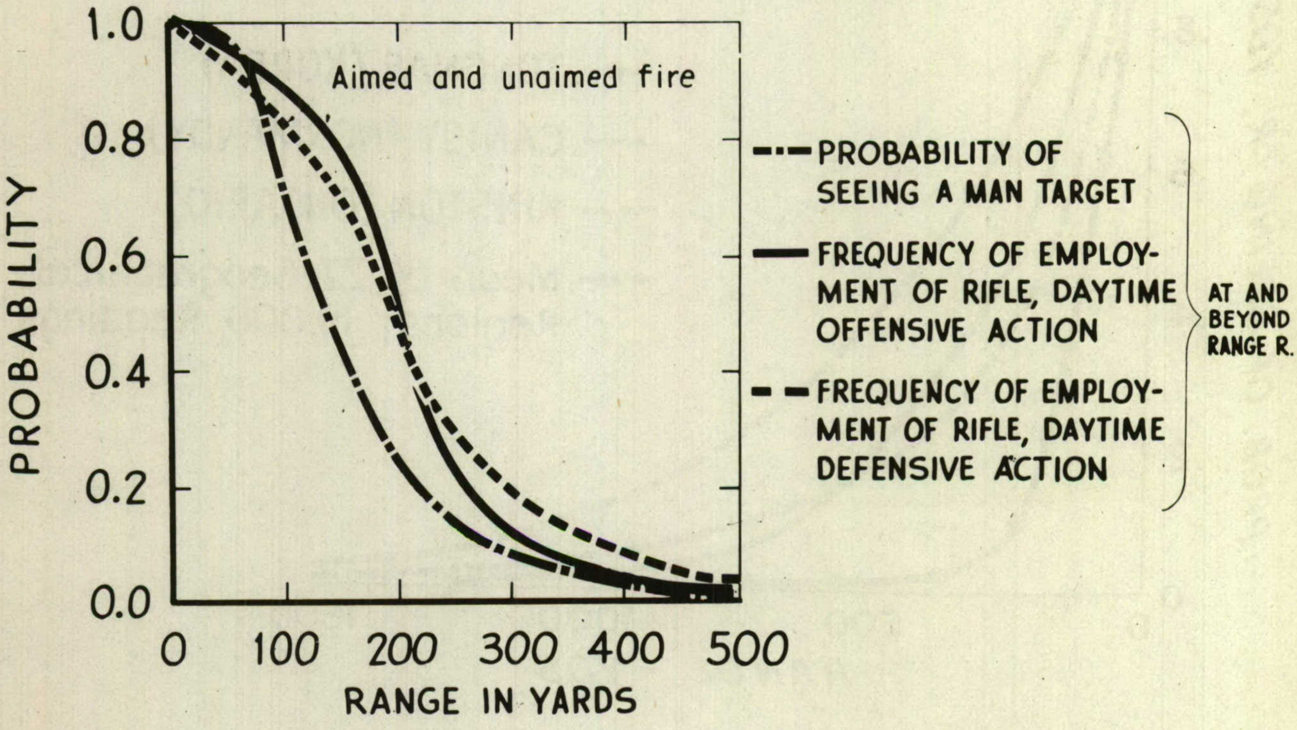

FIGURE 2

HIT PROBABILITY

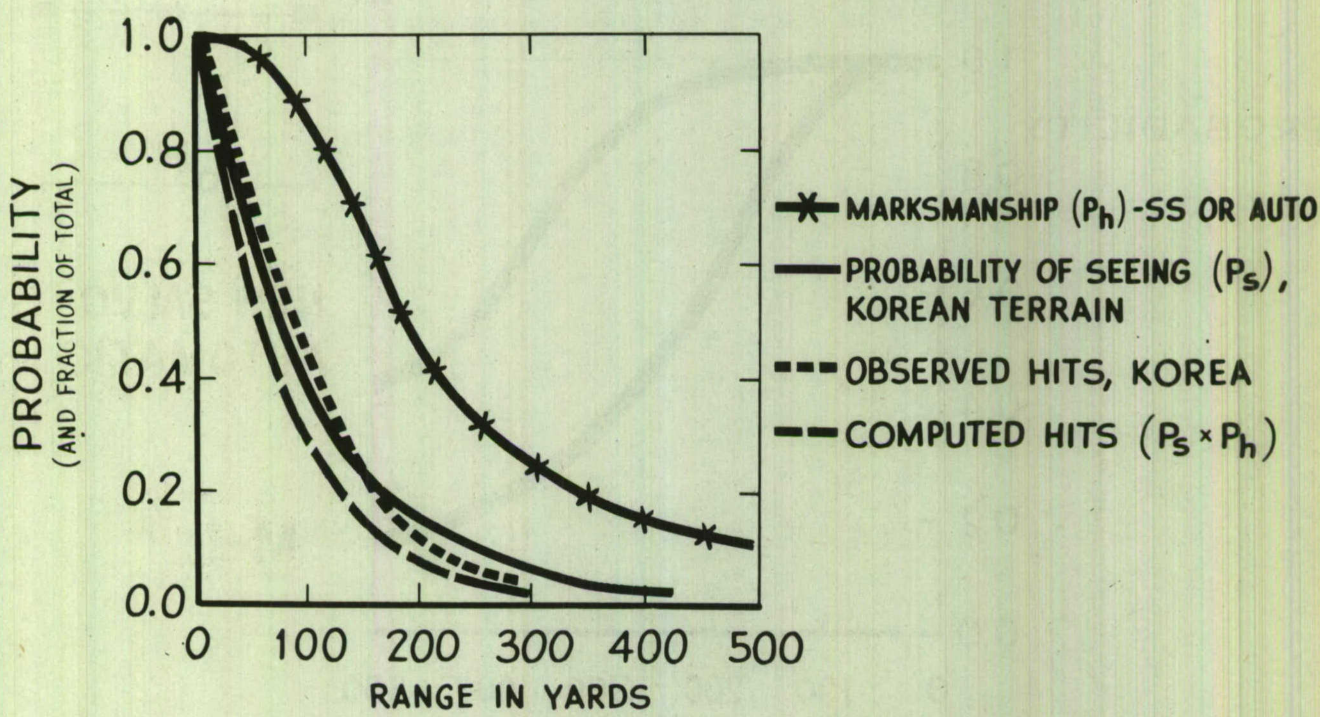

FIGURE 3

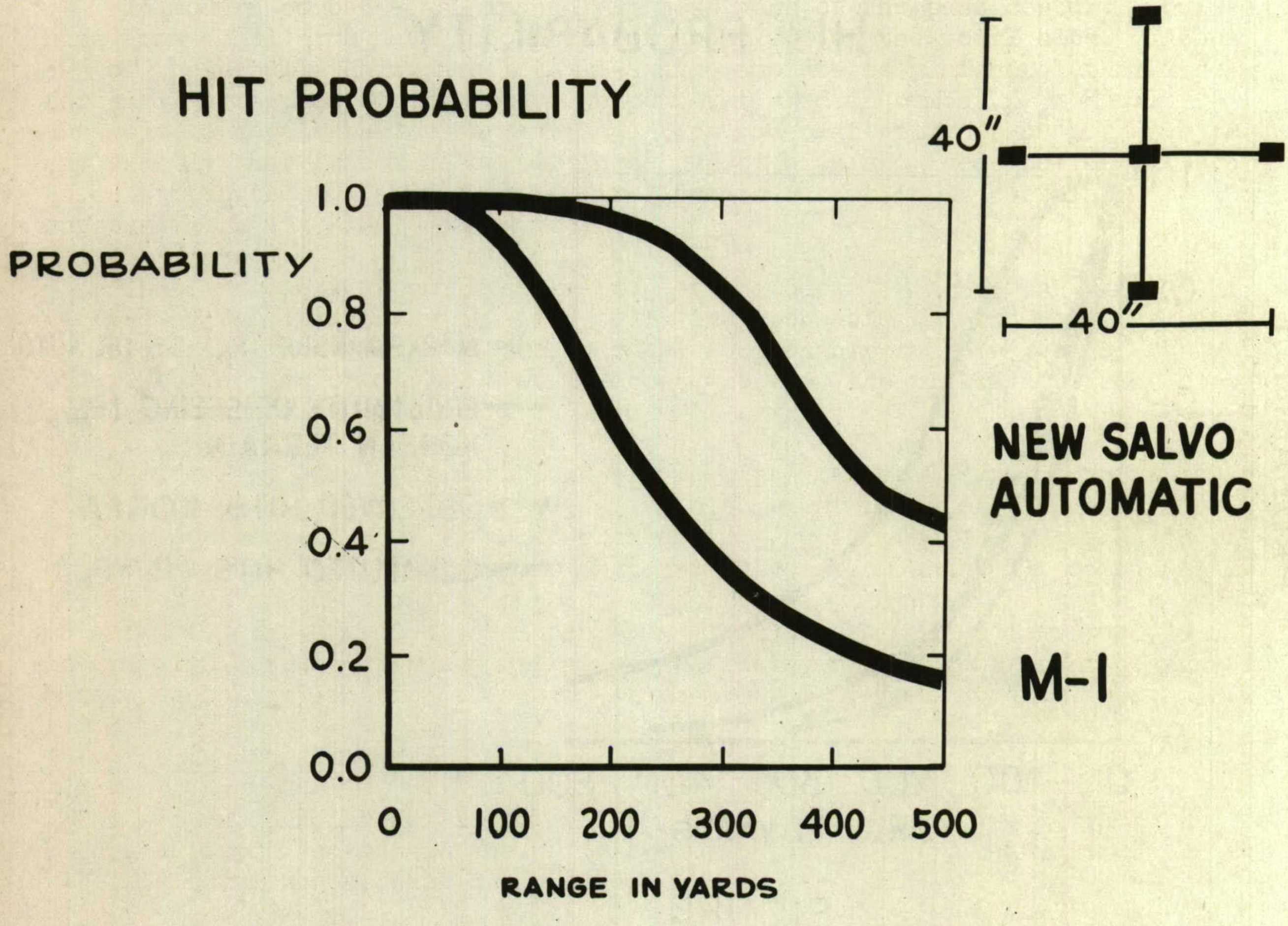
HIT PROBABILITY
PROBABILITY
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
RANGE IN YARDS
40"
40"
NEW SALVO AUTOMATIC
M-1

FIGURE 4

CAVITY SIZE VS VELOCITY

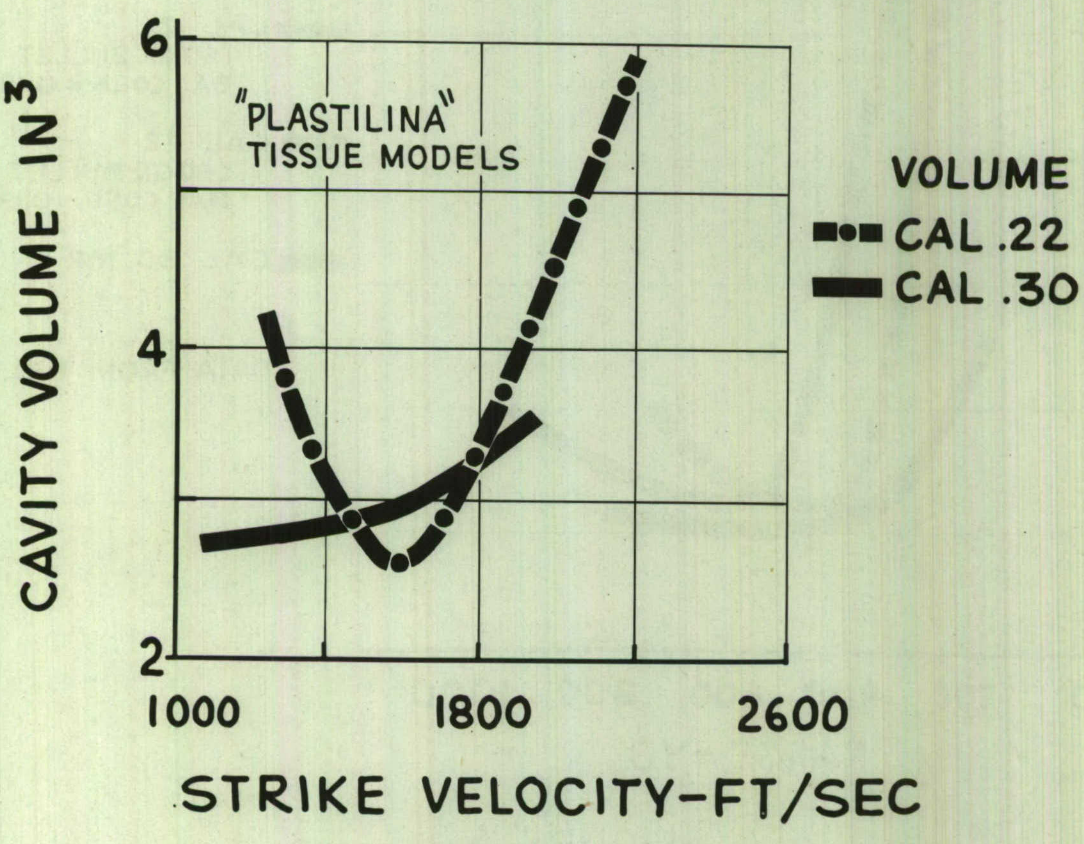

FIGURE 5

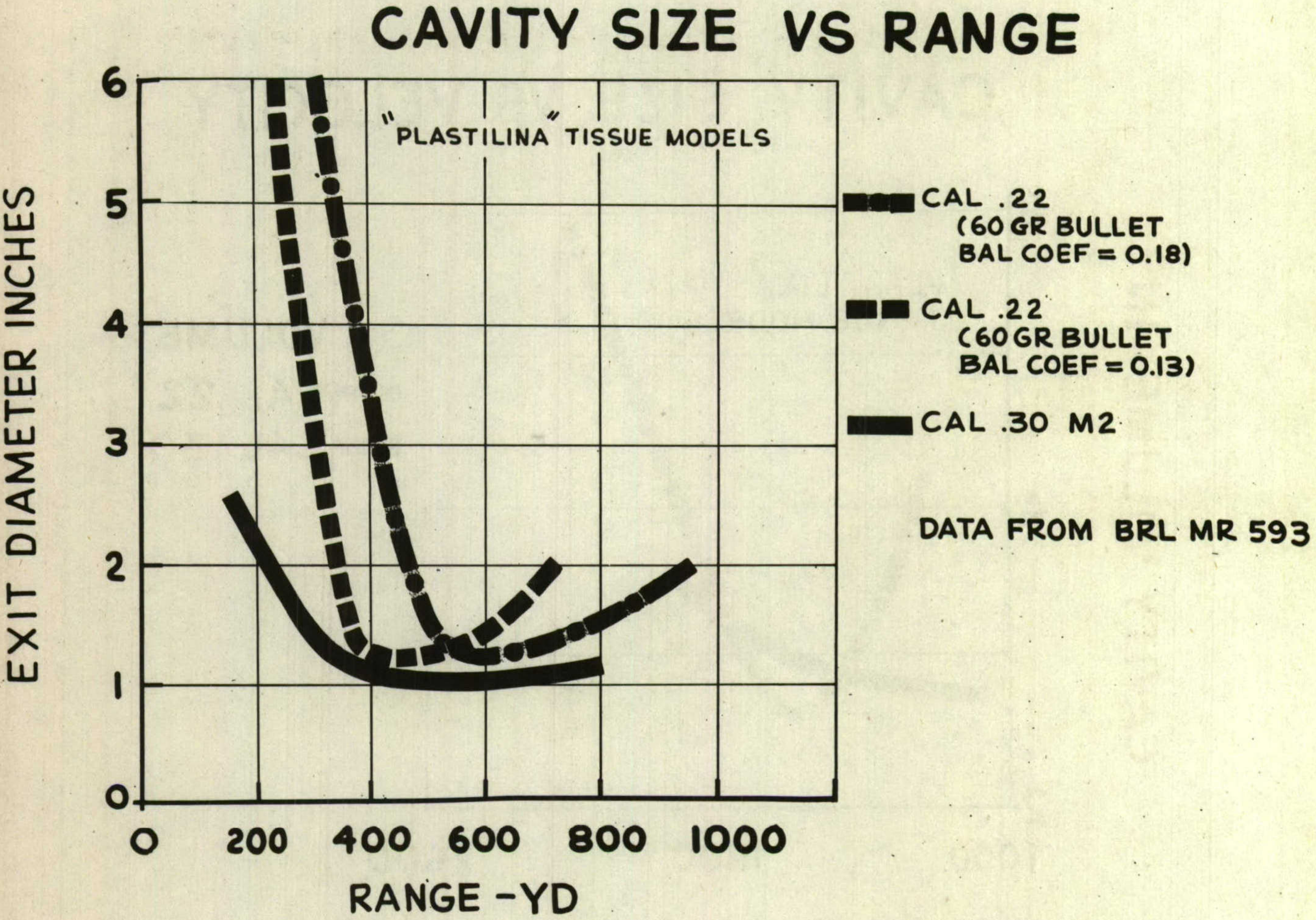
CAVITY SIZE VS RANGE
"PLASTILINA" TISSUE MODELS
EXIT DIAMETER INCHES
0
1
2
3
4
5
6
0
200
400
600
800
1000
RANGE -YD
CAL .22
(60 GR BULLET
BAL COEF = 0.18)
CAL .22
(60 GR BULLET
BAL COEF = 0.13)
CAL .30 M2
DATA FROM BRL MR 593

FIGURE 6

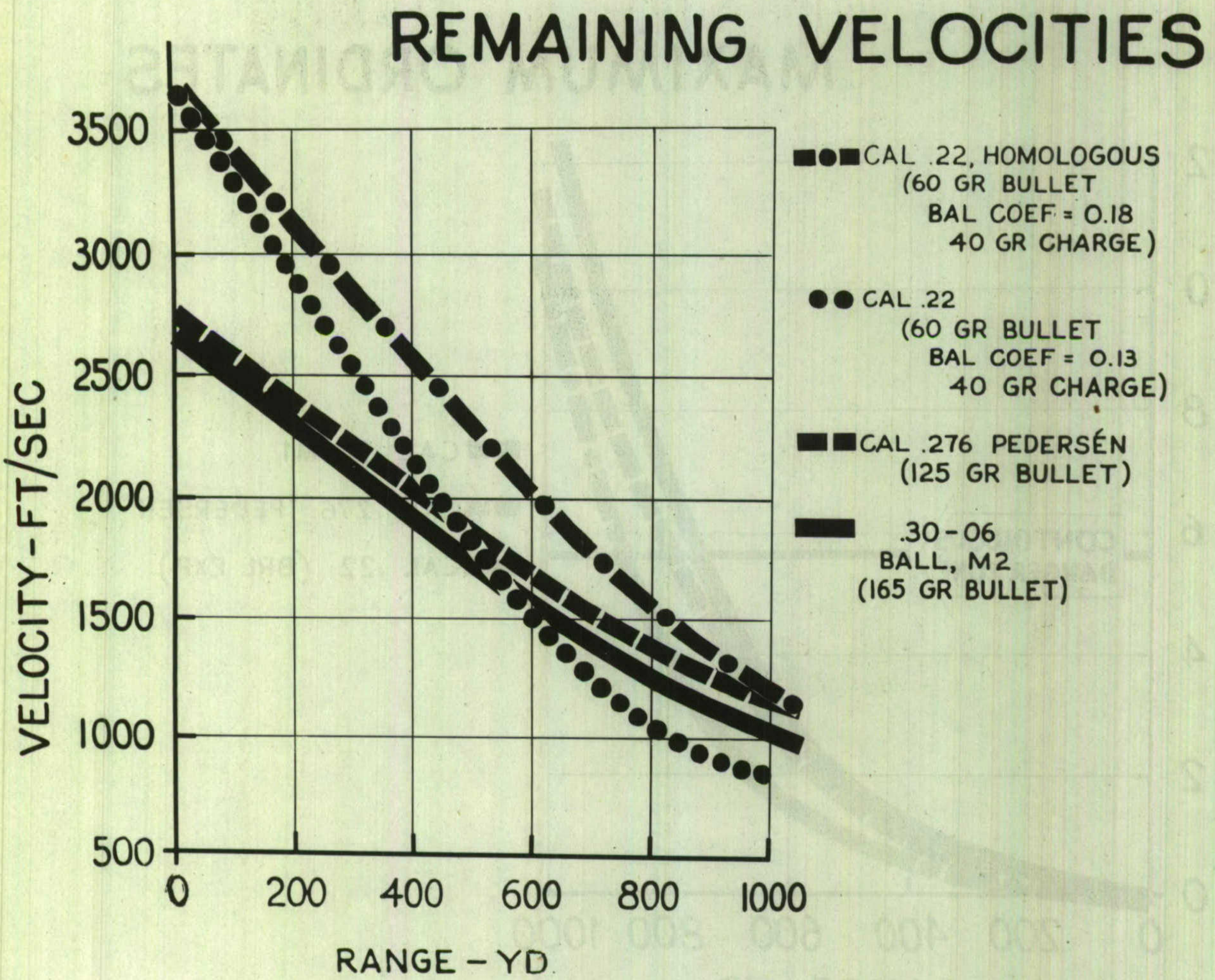
REMAINING VELOCITIES
3500
3000
2500
2000
1500
1000
500
VELOCITY-FT/SEC
0
200
400
600
800
1000
RANGE-YD
CAL .22, HOMOLOGOUS
(60 GR BULLET
BAL COEF = 0.18
40 GR CHARGE)
CAL .22
(60 GR BULLET
BAL COEF = 0.13
40 GR CHARGE)
CAL .276 PEDERSÉN
(125 GR BULLET)
.30-06
BALL, M2
(165 GR BULLET)

FIGURE 7

MAXIMUM ORDINATES

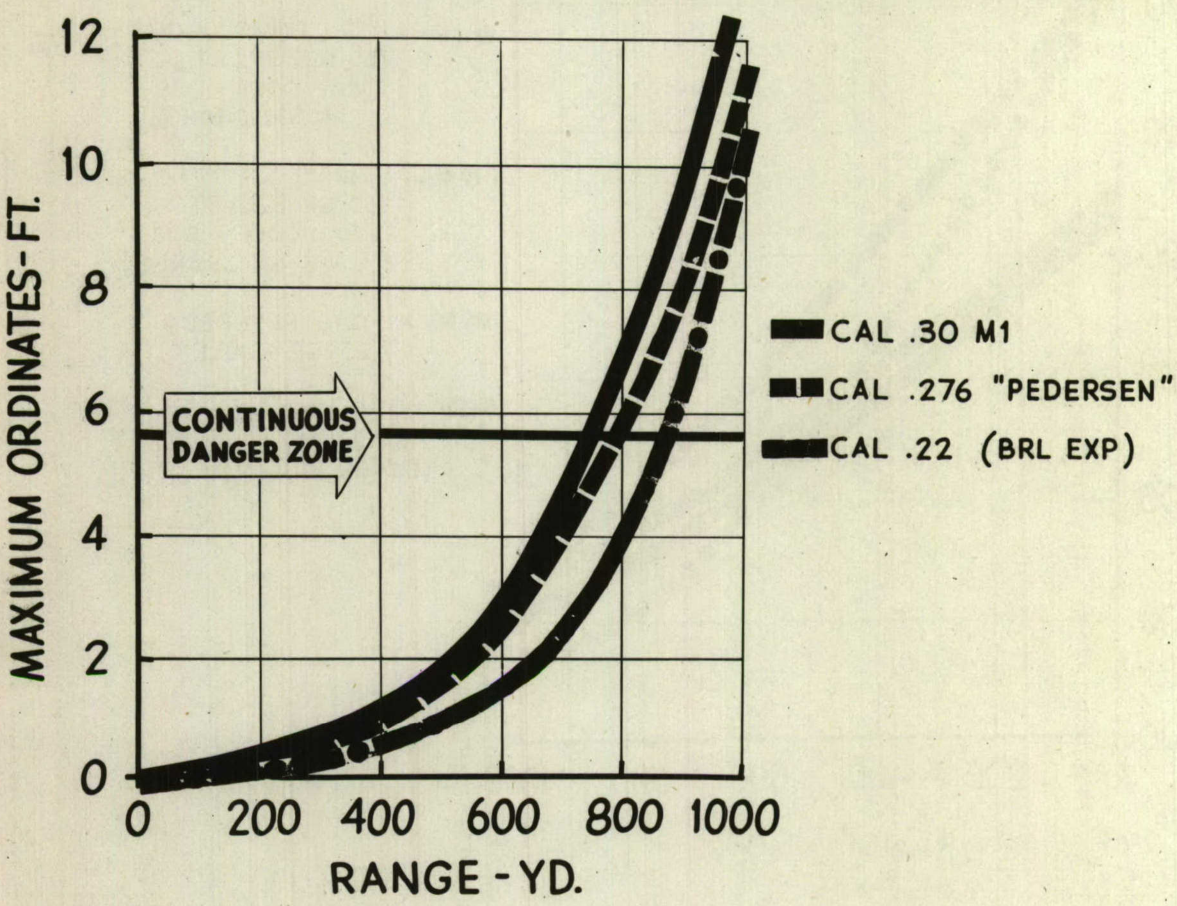

FIGURE 8

FOOTNOTES

1/ The ability of infantry to repel the persistent, continuing assaults of an enemy who can afford to be prodigal in expending his men may well be crucial to the over-all outcome of combat. Although the requirement arises in the first instance from a direct numerical inferiority in manpower, there are other considerations -- related perhaps, but still distinct -- bearing upon the problem of maintaining the integrity of forward positions. For example, it may be anticipated that the NATO allies will be at a distinct disadvantage in fighting the Red Army because of inferiority in three other respects:

1. Heavy tactical air attack, from which we were free in the latter part of World War II and from which we have been in Korea, will have to be faced.

2. The enemy possess a very strong artillery arm, upon which he counts heavily and which he will employ in massive concentrations.

3. The enemy is superior in armor.

A substantial portion of the fires of these outnumbered arms on our side will be subject to a necessary defensive diversion from normal support missions to the direct engagement of their enemy counterparts. Thus, our infantry will find itself largely "on its own". Not only will the customary supporting fires be largely diverted in this fashion, but those few which may remain will be smothered beneath the weight of superior enemy capabilities in kind. In the first phases of hostilities, at least, the tactically important task of killing the enemy will fall in unaccustomed measure upon the infantry.

As an illustration:- Aside from his large numbers, the recent enemy in Korea was in something like the position we must anticipate if we fight the Soviets in Western Europe. The fraction of our casualties in Korea resulting from small arms fire is 65% greater than it was in World War II. (In World War II, 20% of all hits were from bullets; in Korea, 33% of our WIA and KIA have been those hit by bullets). Such a figure reflects the unwonted importance of small arms to a force relatively deficient in air, armor and artillery. (Of course, it may be said that this is just an example of one weapons family replacing others, and thus necessarily accounting for a larger than usual share of total casualties. However, in Korea, our aggregate casualties are not being incurred at any comfortingly reduced rate. And certainly there is clear indication here of the heightened importance of improving small arms fire -- rifle fire included -- as that fire tends to become the principal means - especially so if infantrymen will be few in numbers).

It is perhaps true that, as a result of World War II experience, our infantry's confidence in and reliance upon rifle fire has tended to decline. There has been an inclination to regard the Korean experience as something of a military anomaly, and to view the emphasis attaching there to the purely infantry role as a departure from what is typical of a full-scale modern war. - Yet even from Korea there is evidence at every hand of a growing tendency to call for more and more artillery, more and more armor, more and more air strikes. -- All this is poor preparation for a future in which the enemy, not we, will have "more and more" of all these supporting weapons.

2/ The lethality of the fragment missiles -- as from bombs and shells -- is only 17%.

3/ Apparently 30 - 45%, from the 40% of total small arms ammunition expenditure which is used in shoulder weapons. (Such an estimate can be preliminary only and is subject to revision as study continues. Some fairly sizeable samples show rifle fire probably accounting for only about 20% of all small arms hits while involving some 60% of total small arms ammunition expenditure (expressed as rounds). Such samples show the possible range of variation from the trend of the data thus far available.

The first figures, 30 - 45% of total bullet expenditure, are the best at hand).

4/ "Stopping power," quite properly given a premium value by the Ordnance Corps and the OCAFF, depends principally upon whether a vital organ, nerve center, important skeletal member or muscle complex is hit or immediately affected. To the extent that an actual hit on a particular spot is required, this characteristic is quite independent of caliber, muzzle energy, terminal ballistics, or any other design feature -- provided only that a reasonable penetration (for which a strike energy of about 60 ft.-lb is normally sufficient) is obtained. To obtain such hits would require directing the bullet at a particular and vulnerable body area -- a performance quite beyond the ordinary rifleman.

The only feasible control, (and it is only a partial control) over "stopping power" that remains is to reduce somewhat the requirements for hitting a particular spot. Transferred strike energy, as basically a function of terminal ballistics, may be adjusted to provide for formation of a temporary wound cavity sufficiently large to include or affect a nearby vital region which may not actually be hit. In the capability for inflicting wounds of such extended physiological effect, the small caliber, high velocity round is distinctly superior (as will be brought out later). However, improvements in instantaneous "stopping power" through any design feasible for a hand weapon are probably severely limited. What is needed for major improvement is commensurately better aiming at vulnerable areas, which does not appear possible of achievement even by the method suggested in what follows for increasing hit probability. -- The tactically important immediate incapacitation is an extremely difficult matter.

5/ See footnote 3/

6/ What this ratio means in terms of relative dollar costs per hit or kill is not readily to be computed. Although it is probably a cheaper than average weapon within present tactical patterns, the rifle -- chiefly by virtue of its simplicity -- should present a very much more favourable cost vs. effect ratio than most conventional weapons. If one cannot speak both authoritatively and quantitatively in such a comparative sense, it is nevertheless true that, absolutely, the cost per rifle hit (or kill) is higher than necessary. (Preliminary estimates for Okinawa show the immediate direct cost of a rifle casualty to be about one quarter that of a fragment missile casualty. The caliber .30 round costs $102 per thousand. This makes the ammunition cost of a rifle casualty about $1,000 as compared with about $4,000 per casualty for the fragmenting warheads).

In terms of weight of ammunition, 10,000 rounds amounts to about 600 lb. per small arms casualty, as contrasted with about 7,500 lb. per fragmenting warhead (complete round weights).

7/ There is no urgent requirement, however, for actually increasing wounding power. It has a high value now for the rifle, as attested by the lethal index cited earlier.

8/ We do, however, have the indication afforded by the observed expenditure of about 10,000 rounds per hit, as cited earlier.

9/ Recent MC's for the new rifle (as set by OCAFF) specify that, in semi-automatic fire from a bench rest, all shots would fall in a circle of R = 10" at 600 yards. The probability of doing this with all of n successive shots from a machine rest with the M1 is a 42n or .074 for three shots. The CEP for the M1 in a machine rest is 11.2 inches at 600 yards.

10/ Short burst automatic fire at 100 rounds per minute for 15 minutes is specified.

11/ A principal point to be drawn is that MC's are often unrealistic or meaningless. Here one might well ask -- without being guilty of forcing

a quodlibet, since this is a technical matter -- by whom, or how and in what time, "all" shots could be fired.

12/ The torque resulting from the non-linearity of the axis of effort and the center of resistance (in the conventional design) causes the muzzle to rise; the torque caused by the eccentric loading of the man (right shoulder instead of center of gravity) causes rifle and man to turn to the right. Target "walk-off" is consequently to the upper right.

13/ The order of the improvement is indicated by the computed hit probabilities for 300 and 500 yards of .85 and .43 respectively, which contrast with the present single shot values of .35 and .15 (average marksmen). Kill probability at 200 yards is raised to .41 from .13.

14/ Gufstafson of Aberdeen Proving ground. The cyclic weapon appears, at the moment, most practicable. Controlling the length of burst is a problem to be solved with this type, and cumulative or total recoil effects with any type. However, both these problems have been solved in past experience for muzzle energies, rifle weights, and cyclic rates of the order under consideration.

15/ Board No. 3, however, recommended the smallest caliber with which effects not less than those of the M1 rifle with M2 ammunition could be obtained. OCAFF overruled. The NATO joint agreement is inexplicit as to caliber.

16/ An illustration common to everyday experience may be found from the effect of pushing a finger into a mass of putty. A slow motion - and hence rate of deformation - requires little force or effort, whereas a greater force and more energy are required for the same penetration more rapidly achieved.

17/ The cross sectional area of the cavity is proportional to v^2; the penetration (length of cavity) to lnv. Consequently, volume varies as v to some power lying between 2 and 3. - From the Princeton observations.

18/ The chosen caliber of the current British experimental rifle, and of the U.S. experimental models made by Pederson and Garand at this time. It should be noted that the .276 presents a ballistically ideal "section density" (for a suitable muzzle energy).

19/ The recommendation of Ordnance was, however, disapproved by General MacArthur, the Chief of Staff, probably through the instigation of General Mosely, his deputy. Colonel Mettler, writing in the Ordnance Magazine of Jan. - Feb. 1952 makes a revealing if ingenuous comment on the way the decision was reached.

20/ There is, however, some reason to be critical of the simulated velocities used in the tests. A bullet in air loses its energy of translation more rapidly than its spin or rotational energy. Consequently, at mid and long ranges the bullet is overstabilized. It is possible that in the Edgewood experiments the tumbling observed in the tissue models was exaggerated in relation to performance at actual ranges.

21/ While maintaining air stability.

22/ The same general effect was observed with the .30 caliber ball, but only at strike velocities exceeding the normal muzzle velocity of 2,770 ft sec.

23/ These experiments were performed with spherical balls. There are certain possible advantages from using round balls as bullets in smooth bore military rifles which should be investigated. (High muzzle energies may be attained with less barrel wear; wear in homologous designs being proportional to weight of charge divided by the cube of the caliber).

24/ The Edgewood tests permit plotting cavity volume against strike velocity and remaining energies for the .30 caliber M2 ball and a homologous .22 caliber bullet. The former is superior for strike velocities less than 2,600 ft sec (remaining energies of 2,250 and 600 ft-lb respectively).

25/ Overall scale reduction is not feasible; but lighter, smaller chambers and receiver assemblies and bolts are made possible. Certain requirements

for length, balance, chamber strength, barrel rigidity, etc., are largely independent of caliber. Furthermore, recoil energies (essentially dependent on muzzle energies) in the neighbourhood of 10-14 ft-lb require a rifle weighing probably not less than 6-7 lb (unless a muzzle brake, always involving some undesirable features, is incorporated).

26/ The ability to penetrate light armor plate is a characteristic of little military value, since personnel upon whom aimed rifle fire is directed are infrequently protected by anything other than the helmet, web equipment (offering scanty protection), and - possibly - light body armor. On this subject see ORO-R-5 (reference No. 15 of the bibliography).

27/ Certain advantages accrue from being able to use the same ammunition for both rifles and machine guns. The range requirement for the latter is 1,800 - 2,000 yards. However, this consideration should be viewed in its proper perspective, and not allowed unduly to prejudice design of the most effective rifle and ammunition. (Continuous danger zones are so short at such ranges as to be of no real value, with present M2 ammunition. For example, FM 23-5, shows that the danger zone at 1,000 yards extends only 100 yards from target toward firer; and from TM-9-1990 it may be calculated for 2,000 yards (angle of fall = 168 mils) as about 30 yards. MG fire at ranges greater than 1,000 yards is sharply plunging - except on reverse slopes where it cannot be observed and corrected anyhow). (It is doubtful that MG fire can ever be observed and corrected at ranges in excess of about 1,200 yards).

28/ Certain limits to the gains from reduced round size and weight, and decreased rifle weight, are unavoidably set for the reasons that:

1. It may be slightly more difficult to manufacture military rifles in a smaller caliber. (However, one may note that the manufacturers of sporting rifles customarily offer many models in a variety of calibers at the same price; any differences in production characteristics are so small that they may be readily absorbed).

2. Barrel wear increases, for a given performance, as the caliber is reduced. This, and certain other factors, suggest that it might be useful to experiment with smooth bore weapons - with which high velocities could be obtained more easily than with the conventional rifled barrels, but the bullets from which would "cool off" rapidly - and also with zinc bullets which would galvanise and protect the barrel of a rifled weapon (See footnote 23).

3. For a given recoil energy, the objectionable forces transmitted to the holder of the weapon increase as rifle weight is reduced (in general, but the time distribution of the force application is also an important consideration). Moreover, the rifle is now, and probably should continue to be in most ways, a multiple purpose weapon. It is a grenade launcher, and a shaft by which they bayonet (a weapon of only marginal value but still in the arsenal) is wielded; it must also serve on occasion as a club.

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MANPOWER FLOW

(Presented by Dr. A. C. Lauriston)

Historical Introduction

As a byproduct of Canada's participation in the United Nations effort in Korea, the Canadian Army Operational Research Establishment - C.A.O.R.E. - developed an offshoot called 1 C.A.O.R.T., first Canadian Army Operational Research Team. This team worked, and is working, with the Canadian Brigade in Japan and Korea; and its program has been controlled directly by the brigade commander. One of its major problems was to collect information on wastage of manpower. The purpose of the project was to provide factual information that would be of assistance in planning measures to control wastage and in planning the reinforcement program for the brigade. The first edition of 1 CAORT studied the experience of the Canadian troops from October 1950 to the middle of 1951 and produced a series of reports on battle casualties, non-battle casualties, crime, medical records, and venereal disease. These reports were of interest but of limited usefulness from the point of view of reinforcement planning because the experience studied was very limited and also because the analysis was made in terms of unit rather than corps and trade - the essential elements in terms of which our reinforcement plans must be made. The second edition of 1 CAORT continued the wastage studies but directed them more towards reinforcement planning by making the analysis in terms of corps and trade. The project was largely one of the collection of factual data. Again the experience studied was of limited extent since it was confined to the Canadian brigade between April 1951 and October 1952. In the past year CAORE has been continuing the study in an attempt to find satisfactory methods for the collection and analysis of wastage information, so that it can be applied more rapidly to reinforcement planning under 'new' conditions. This naturally has led us to explore the more general manpower problem, at least to explore it to the extent that we are able to clarify our own objectives.

The General Manpower Problem

With a limited effort of the sort that is being made at the present time, there are manpower problems. In studying these problems we must remain alert to the possibility of applying this experience to the vastly greater problems of total mobilization. We therefore are interested in finding methods of making even small improvements which would give substantial savings, only in a time of total mobilization.

Let us now take a look at one version of the general manpower problem. Figure 1 illustrates the distribution of the population of a nation among different occupations in a time of peace and in a time of war. In going from peace to war the part of the population that is gainfully employed - that part above the dotted line - is increased and at the same time the proportion of the population in the different occupations is changed. In the process of accomplishing this change there is a tremendous flow of people from one occupation to another. Under the war situation there is a continuing large flux from one occupation to another as our needs for arms and civilian services change from month to month. The general manpower problem may be thought of as the problem of how to control this flow between occupations so that we attain our strategic objective - the defeat of the enemy - and make the minimum sacrifice of the individual freedom of the people of our nation.

I don't think that anyone will claim to have a solution to this general problem. We can however see that there are three distinct, but interdependent, areas of investigation which will lead towards the solution. These are

1. The measurement of our resources

2. Estimation of our requirements

3. Means of allocating our resources to fulfil these requirements. The work of 1 CAORT and CAORE has been entirely in the second area. Within this area our work has been confined to a much smaller sub-area. We have not concerned ourselves with essential civilian production, or military production

requirements for manpower. We have restricted ourselves to the armed services and in the armed services we have considered the army only and in the army we have looked at only a very small part of the picture.

Figure 2 shows the flow of manpower into the armed services. We start with a civilian population. People come from the civilian population to one or other of the services. The beginning of the army channel is an induction centre or a personnel depot where the man is allocated to one of the corps schools or unit depots for training. Following the army channel, there are two more stages, a training stage and a service stage. These three stages have a similar flow pattern. So far we have only studied the last stage, the service stage, which is illustrated in figure 3. There is a principal imput which consists, at the theatre level of drafts of trained men coming from Canada. Enlistments in the theatre, or re-enlistments may be thought of as a secondary imput. Permanent losses such as death, discharge from the services, and return to Canada for a variety of reasons occur. Temporary losses for medical treatment, disciplinary and administrative losses combine to produce a rather full pipeline of non-available people in the theatre. Because of these losses the output, which is the return to duty of those who have completed their rotation tour, is not an exact replica of the imput. The unit which 1 CAORT studied was a brigade group in a theatre of operations, Korea from 1950 to 1952.

The Korean Experience

1 CAORT worked almost entirely from the records of service of the individual, or rather, from those portions of the service record that were abstracted in various card index systems maintained by No. 2 Canadian Administrative Unit. This, of course, was supplemented by quite a bit of talk which supplied background information and ideas concerning the accuracy of the data. Limitation of the sample size to include only the bulk of the experience of the Canadian brigade was made necessary by the small size of the team and by the need to study other problems.

I will now show you a few results of the analysis that was made. Many of the differences shown cannot be said to be statistically significant. This is, however, a reasonably accurate picture of what did happen.

(a) Time lost in the theatre

Figure 4 shows the distribution of time lost for the brigade over the different types of loss. This time lost is expressed as a percent of the total time available for duty. All persons posted to units, attached or seconded to units, available as reinforcements, or on courses are considered to be available for duty. Those who are awaiting return to Canada are treated as though they had already left the theatre. Time spent by battle casualties, either in hospital or awaiting disposition - which generally involves a medical decision as to whether they are capable of further service - amounted to about 1%. Time lost by non-battle casualties amounted to about six and one half %, of which 1% resulted from accidents one half of one per cent from V.D. and about one tenth of one per cent for mental ailments. Accident includes those cases where the diagnosis mentioned non-battle wounds, burns, fractures, sprains, bruises, dislocations and lacerations. Venereal disease includes a vast host of symptoms a portion of which might not have been venereal disease. Mental includes neuroses, hysteria, anxiety state, battle exhaustion and psychiatric consultations. The other sickness category, which amounted to a little more than two per cent includes all other hospitalization. Awaiting disposition amounted to about two and one half per cent. It includes the same sort of medical decision as for the battle casualties as well as administrative problems and administrative delays. It also includes a fairly substantial number of people who were doing jobs in base areas but were surplus to establishment. This mal-use of personnel - or at least poor recording - was corrected after a few months but it does introduce considerable doubt as to the likely size of this time loss in another new theatre. In all the total time lost amounted to about eight and one half per cent of the time available for duty.

(b) Battle casualty rates by Corps

Figure 5 shows the battle casualty rates for each corps, expressed as a

per cent of the force per month. The long bar is the infantry battle casualty rate which was about one tenth of one per cent of the forces per month. You can see that the infantry corps casualty rate was over three times greater than the rate for any other corps and was almost twice as great as the average rate for the whole force. These rates apply to the entire population of each corps whether or not they were exposed to any battle risk. If we had not included in the infantry those people who were behind battalion headquarters, and had not included the time when the infantry battalions were in reserve the infantry battle casualty rate would have been about 50% greater.

(c) Non-battle casualty rates by Corps

Figure 6 shows the non-battle casualty rates for each corps. You can see that the casualty rate was not greatly different for the different corps, being from five to eight per cent of the force per month for the corps shown here. However, these differences in casualty rates are great enough so that it would be quite worth while to take them into account in our reinforcement planning. One difference which is not shown on this diagram but which we observed was that the smaller corps had extremely small non-battle casualty rates. The dental corps and pay corps rates being about 3% per month. It may be that all small specialist groups have low non-battle casualty rates. This is borne out to some extent in our analysis of particular trades in the larger corps although it does not seem to be a fact that is universally true.

(d) Time lost in theatre for each Corps

Figure 7 shows the total time lost in the theatre for each corps expressed as a per cent of the time available for duty. The differences in the time lost were greater than the differences you would expect from the differences in casualty rate. This is because there was a difference in the rate of recovery in the different corps. The time lost by the infantry corps was high - about 10% - and RCEME was low, - about 5%.

(e) Rate of loss from theatre for each Corps

A head count was made of those people who left the theatre prior to their normal rotation date. We subtracted those people for whom there was good reason to believe the loss was a premature but otherwise normal rotation. Figure 8 shows that there were considerable differences between the corps loss rates expressed as a percent of the force per month. The infantry corps and medical corps were high - about 2% per month -, while armoured, signals and ordnance were low - a little greater than one % per month. For estimating reinforcement requirements, however, the data should be treated with considerable caution. For example, an RCEME unit in the theatre was dissolved. This left a surplus of skilled tradesmen in particular trades in the theatre. There was no prospect of their finding suitable employment before they were due for rotation so they were returned to Canada early. We were able to identify this group and they are not included in the loss rate shown here. Unless we are fairly certain that not many were returned to Canada because they were surplus then we may expect that the loss rates obtained by this simple method will be high. As a matter of fact losses were rather high, at least as a per cent of hospital admissions. In general only about eighty per cent of non-battle hospital cases recovered and were returned to duty. Other experience has indicated that the rate should be as high as ninety to ninety-five per cent. The reason for the high loss may be that there was a rotation system in operation which was accompanied for a time by a rather lenient attitude towards sending casualties home early.

(f) Variation of non-battle casualty rate with month in the rotation period

The list of particular points which we have looked at in our study is long - too long to go over them all to-day. I will therefore mention only two more, the two that we have used in some computations with a theatre model. The first is the variation of non-battle casualty rate according to the month in the rotation period. This is shown in figure 9 where the casualty rate as usual is expressed as a per cent of the force per month. The top of the block represents the observed casualty rate. It was significantly low in the first and second months and high in the third, fourth and fifth months. It then

levelled off and fluctuated about an average value for the rest of the year. At the end of the year there was some indication of a slight decrease in the rate. I would like to be able to say that we have sorted this thing out and that we know this to be an effect due to the time in the rotation period and not due to the month in the year. We have not done all the sorting we would like, but we have done some sorting and think that the effect is real. At least it does have a logical explanation. By pre-embarkation medicals we have screened out a lot of people who would have developed ailments even if they had been in Canada. After this casualties start to occur among those who are susceptible to some particular phase of their new environment and don't take the proper precautions. In the levelling off we may think that we have weeded out the few who were most susceptible and have acclimatized the rest. The slight decrease at the end of the year may be due to the fact that early return to Canada is anticipated and the men do not want to go to hospital since they know that this will probably mean a delay of one or two months in returning home. The dots on the graph indicate the casualty rates that we have used for our theatre model. We have assumed fixed casualty rates which change discontinuously at the end of each month. For the later months we have assumed a steady casualty rate, neglecting the small decrease immediately before rotation. This has been done to simplify computations.

(g) Return to duty of non battle casualties

The last element of the Korean experience which we wish to mention is the duration of hospitalization until return to duty for non-battle casualties. This is shown in figure 10. The cumulative total of % returned to duty is shown as a function of the number of days after admission to hospital. The smooth curve is one calculated from an equation of the form

$$B=R_1\,(1-e^{-at}) + R_2\,(1-e^{-bt}).$$

The points, which are the observations from Korean experience, show that the equation fits our experience very well.

(h) Comparison of return to duty equations

This visual goodness of fit rather intrigued us so we went ahead fitting similar equations for other experience upon which we had data readily at hand.

Battle casualty returns to duty in the Korean experience, battle and non-battle casualty data for US troops in the European Theatre of Operations in World War II, and some civilian experience in the United Kingdom in the winter of 1943-44 and in the summer of 1944 were fitted. In each case the fit was remarkably good. In the case of the US battle casualty data however it was by no means as good as the one shown here.

The constants that were used in fitting these different sets of experience are shown in figure 11. The first terms of the expression contributes the long term illness and a small part of the short term illness. The second term contributes the very short term illness only. These are not very important from the point of view of reinforcement planning. It is interesting to note that in the battle casualty experience, a term to represent a large amount of short term illness is not required. This is an indication of the fact that the condition of being a battle casualty is something that is quite clearly defined. Battle casualties don't go to hospital for scratches or for observation to detect some possible ailment. The condition of being a non-battle casualty, on the other hand, is rather more difficult to define, since the situation of the unit, and its prospective operations, and the job of the individual man, will determine to a certain extent, whether that man is admitted to hospital. At times the unit can take care of him and at times they can't. This sort of curve fitting seems to be a useful device for sorting out the very minor form of illness from the moderately serious illness. The fact that both time constants for the Korean experience are nearly the same indicates that the time constant may be a characteristic of the medical services. I do not know whether the American battle and non-battle casualties in Europe during World War II received the same type of medical care. If they did then the American experience refutes this possibility. The British experience in the summer of 1944 is of

interest because the return to duty is not greatly different from the Korean experience and the American battle casualty experience. The winter experience of an intermediate recovery rate is due to the prevalence of a single ailment, namely influenza, during that winter.

The Theatre Model

The data illustrated in the previous two figures has been used in some simple calculations with a theatre model. The theatre model is shown in figure 12. The imput into the theatre is composed of drafts sent from Canada. There are in addition some people who elect to serve a longer tour or who enlist in the theatre. These are the subsidiary imput. We have neglected any subsidiary imput in our computations. Throughout the rotation period losses occur from the theatre population. We have restricted ourselves to considering only the losses that result from non-battle causes, since these contribute the greatest part of the loss, and since with these it is more reasonable to assume that an exact casualty rate applies in each period with no accidental distribution about a mean value. Starting with an arbitrary size of available force - ten thousand was used - the number of casualties occurring in the force in each five day period was calculated assuming that the casualty rate varied with month in the rotation period in exactly the fashion shown in the earlier diagram. It was then assumed that these casualties returned to duty exactly as was described by our return to duty curve. The permanent losses are the non-recoverable portion of the hospital admissions. The output is the return to Canada of those who have completed their rotational tour.

Population Decay of the Model

The result of the computations is shown in the population decay curve of figure 13 - we may also think of this as a life curve. The rate at which the population decreases is not uniform. This non-uniformity can be very useful to us if we can identify that it is due to general causes which are not particular to our Korean experience. We have assumed discontinuous changes in the casualty rate. These changes go to produce kinks in the curve. At the end of the first year only eight thousand five hundred of the original group are still available for duty. Many of these will have been casualties and will have recovered and returned to duty.

Figure 14 shows how this deficit was distributed at each time during the year. A part of it is in hospital and will recover if given time. A part of it is in hospital but will not recover. The remainder is made up of the non-recoverables who have left the theatre. This part was found by assuming that each non-recoverable casualties left the theatre exactly fifty days after he was admitted to hospital. This was the average time after admission to hospital when the non-recoverable, non-battle casualties of our Korean experience left the theatre.

Figure 15 shows the number of people returned to duty from hospital in each five day period. Let me emphasize again that these are the results of computations with a model and are not the results of observations made on the theatre directly. This return to duty curve closely parallels the casualty curve since a very large part of the recoverable non-battle casualties returned to duty within the first fifteen days. The return to duty curve is low initially because the hospitals are still empty. After the casualty rate decreases in the sixth month it is a long time until the return to duty curve levels off.

Effect of Rotation Period on Wastage Allowance

Using our life curve for the theatre model (figure 16), we have computed the number of men required to supply a force of one thousand men for a period of one hundred months with different rotation periods. Since it is calculated from the previous life curve it is based upon the same assumed variation in the casualty rate according to month in the rotation period, and the same assumed return to duty curve. It is further assumed that the casualty rate remains the same in the thirteenth and succeeding months and that the return to duty curve is not influenced by length of rotation period. The upper curve

represents requirements taking into account non-battle wastage; and the lower curve the requirements if there were no wastage. The difference between these two curves represents, then, the allowance that must be made for wastage.

This difference - the wastage allowance - is shown in figure 17.

This is a peaked curve with the peak between four and six months. For a twelve month rotation period about eight hundred and eighty men are required to allow for wastage in this ficticious thousand man force operating for one hundred months. Decreasing the rotation period would require a greater allowance for wastage as well as a greater number for rotation. On the other hand, increasing the rotation period - within narrow limits - would give a saving both ways. The allowance required for wastage varies according to the rotation period but the variation is quite small. This is the sort of marginal improvement that would make a great saving only if we were working with a very large force.

Comparison of Rotation Schemes

The life curve was also applied to the study of three different rotation schemes. The schemes considered are shown in figure 18. The first scheme is one in which the unit is sent at the beginning and allowed to decay until the end of twelve months when it is replaced by a new unit. There are no individuals to be rotated apart from the main group. In the second scheme a full unit is sent at the beginning of each year and the unit is reinforced monthly to bring it to its establishment strength. We have worked with an arbitrary establishment of ten thousand men. Individuals who arrive apart from the main group are rotated on their appropriate rotation dates. In the third scheme we start initially with a full unit of ten thousand men. This unit is then brought up to establishment strength at the beginning of each month. There is no unit rotation but all individuals are rotated on their appropriate rotation dates, unless they have been invalided home earlier. It is assumed throughout that the same casualty rate variation in the period of the rotation applies to each separate draft arriving in the theatre.

(a) Scheme 1

The month by month situation resulting from scheme 1 is simply the population decay curve which was shown in the earlier figure. It shows merely a theatre deficit building up.

(b) Scheme 2

Figure 19 shows the month by month situation with the second scheme. The height of the columns represents the monthly demand for reinforcements. The part of the demand that arises from actual theatre deficits is shown in heavy cross-hatching, while the part which is caused by the need for rotation people in the theatre is shown in light cross-hatching. The dot hatched columns represent theatre surpluses rather than theatre deficits. The tall bar at the beginning of each year represents the rotation of the unit and extends way off the scale - up to ten thousand. Some of the surpluses also extend off the scale. In the first year all reinforcements are required to fill theatre deficits and the demand changes roughly as the casualty rate although the demand is higher in the first months because there are very few people coming out of hospitals. When the casualty rate decreases slightly the demand decreases more abruptly because of the supply of men coming from hospital. The hospitals soon lose their excess however and then the demand levels off at a value which is about the same as that for the first month when the casualty rate was only a third as great. After the first unit rotation there is a surplus in the theatre for three months and in the fourth month the demand is entirely to replace those who are due for rotation. In the succeeding months the demand is relatively stable at about 200 per month for the remainder of the year. After the second unit rotation there is theatre surplus for five months, a month of pure rotational demand then a stable demand of three hundred per month for five months. After the third unit rotation the theatre surplus lasts for six months then after a month of pure rotational demand there is a stable demand of about three hundred and fifty per month. The system is very flexible and very strong. It depends however upon our ability to send a complete unit to the theatre at

the beginning of each new year.

(c) Scheme 3

The month by month demands of the model theatre arising with our third rotation scheme are shown in figure 20. The cross-hatched columns again represent wastage and rotational demands. In this scheme we have no theatre surplus. The first year, of course, is precisely the same as with the second scheme. The number of men required to fill the large demand at the beginning of each new year gradually decreases however, being about eight thousand five hundred in the second year, seven thousand two hundred and fifty in the third year and six thousand two hundred in the fourth year. Demands during the year increase year by year and there are large month by month fluctuations. The peak demands in successive years are about three hundred, five hundred and thirty, seven hundred and eight hundred and thirty. In those months where wastage demand was high it decreases year by year; in those months were it was low it increases year by year.

(d) Comparison of three schemes

Now let us turn to a comparison of the three schemes as shown in the next figure. For the three schemes the average of the monthly deficit occurring during the first four years is about one thousand, one hundred, and about one hundred and fifty. The first scheme is very bad from this point of view: the more so because its deficits are of extended duration while those of the other two schemes are shorter. Scheme two is better than scheme three in terms of the size of deficit that occurs, in fact, it produces a surplus for fourteen of the first forty eight months. The relative cost of the three schemes can be measured by the number of men required to maintain them. The first scheme is certainly the cheapest since it requires only ten thousand men per year to maintain, if we may use the word maintain to describe this system where large deficits for extended periods are allowed. You could of course reduce the deficit by increasing the initial level above that required by the establishment. To obtain an average monthly deficit of the same order as that in schemes two and three would require an additional fourteen hundred men per year for scheme one. One suspects that starting a new unit at the beginning of each year with such a plush establishment would cause a lot of pleasant but unnecessary jobs to develop and that these would be difficult to weed out later in the year when the shortages started to develop. Of course, the same objection can be held against the second scheme. The difference year by year in the cost of maintaining schemes two and three would be, nothing in the first year, 43, 94 and 147 men in the second, third and fourth years respectively favouring scheme three over scheme two in each case. In four years scheme two would cost only two hundred and eighty four additional men. This, however, is not the complete story. If the theatre is to continue in operation for an indefinite time we must also take into account that scheme three has a reserve of potential service in the theatre which is eleven thousand six hundred man months greater than for scheme two. Taking into account the theatre life expectancy of a new man arriving in the theatre this is equivalent to about one thousand new men supplied. This difference goes to build up larger additional costs of scheme two over scheme three in subsequent years.

Future Work

Now for a few final comments about things we haven't done yet, but would like to do, or are trying to do. One of these, and a most important one is to get away from this model where we use only mean values and assume that the casualty and return to duty curves have no accidental distribution about the mean. We would also like to take into account battle casualties but these will probably occur in packets localized in short time intervals and the adequate description of a battle casualty rate will, therefore, be more difficult. Our estimate with the theatre model so far are really minimum estimates since they do not take into account battle casualties. It might be noted though, that historical experience, particularly in Korea, generally shows that non-battle losses are greater than battle losses provided we obtain rates for the whole of a campaign rather than rates for a single battle.

A second thing we would like to do is to extend our model taking into

account the size of the group to be reinforced. It would seem reasonable to expect that the relative economy of maintaining a small unit would be less than that of maintaining a large unit, simply because of the unlikelihood of the man coming out of hospital just when he is needed. As yet we haven't done anything about this but it seems to be quite important since we are dealing quite frequently with relatively small groups trained in a particular trade.

A third bit of work that we haven't gotten under way yet is the collection of data from other historical campaigns using records of service of the individual. This would be done to establish what parameters are general and what ones are specific to the particular theatre which we have been studying. All of the information gotten from Korea, apart from some general background, could have come from records of service, and all of it did pass through machine records at some time. It is therefore conceivable that systems could be installed to collect not only historical data, but also current information and to provide cumulative totals of this wastage information on which we could base policy decisions concerning our reinforcement planning. This would involve some theoretical statistical work to decide upon the amount of data and the difference in rates that must accumulate before we are justified in modifying our wastage tables in favour of the new current rates. These jobs are still in the future. With our limited resources I am quite sure that it will require a long time to complete them all.

Summing up

This paper has been given to describe an operational research approach to a particular problem. The approach starts with a question. How can we improve our reinforcement programme? It proceeds logically to data collection which establish the facts of the case. Parts of the data were then used in computations with a mathematical model. From these computations we gave some quantitative insight into the manner in which wastage affects our reinforcement planning. This insight may be of assistance in making reinforcement plans immediately. Whether or not it does this it leads to identification of the more important avenues for further study.

(a) The effect of accidental distribution about the mean in casualty rates and return to duty curves.

(b) The effect of size of unit in economy of reinforcement

(c) The identification of parameters to describe wastage for historical campaigns

(d) Methods of collection and analysis of current wastage data.

If there are any questions concerning the work discussed here I will try to answer them. For the more general questions on manpower planning I am sure that there will be others present who are much better informed than I.

FIG. 1.

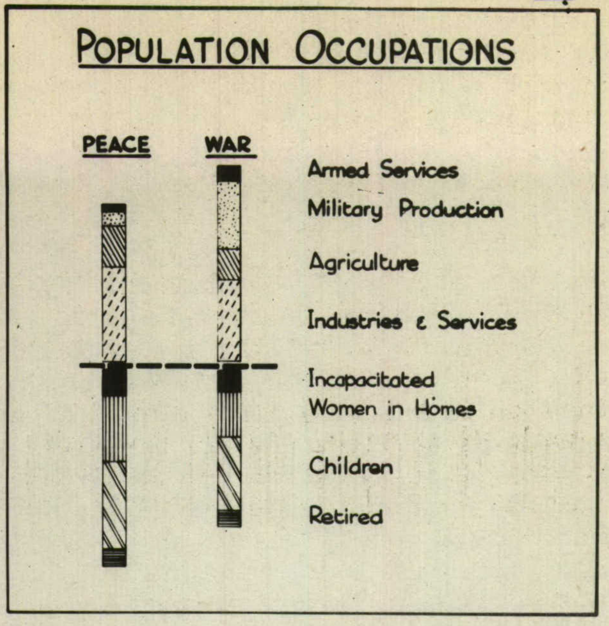


FIG. 2

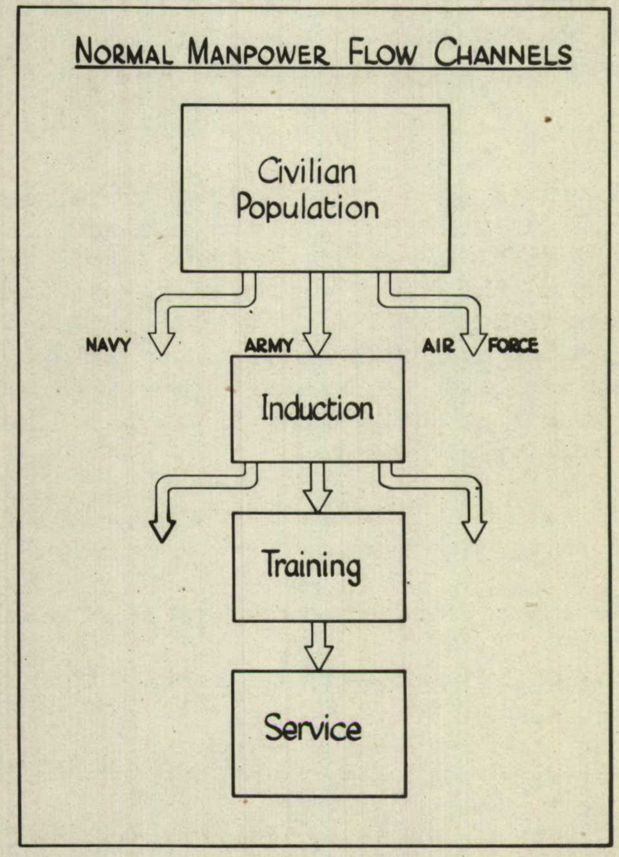


FIG. 3

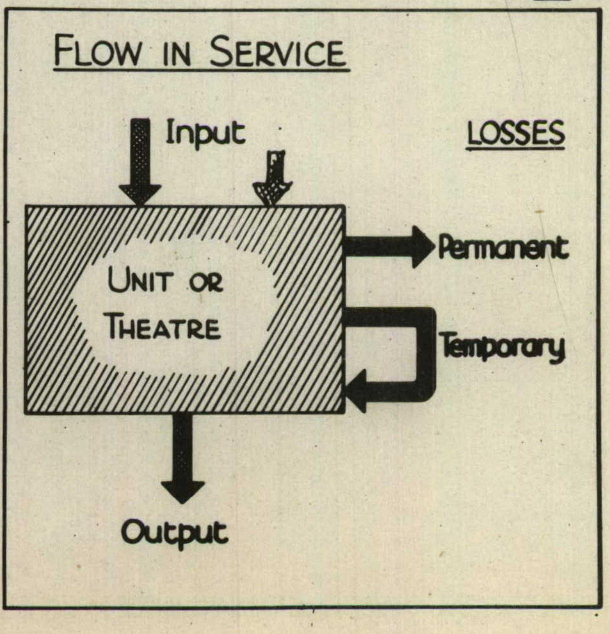


FIG 4

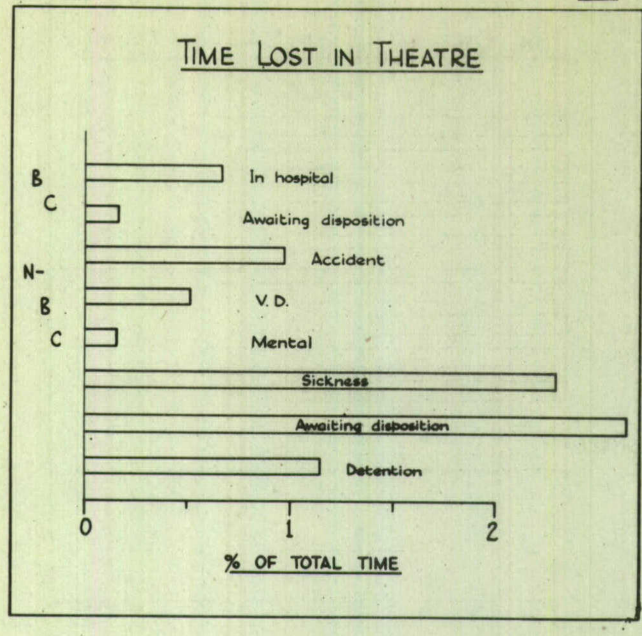


FIG 5

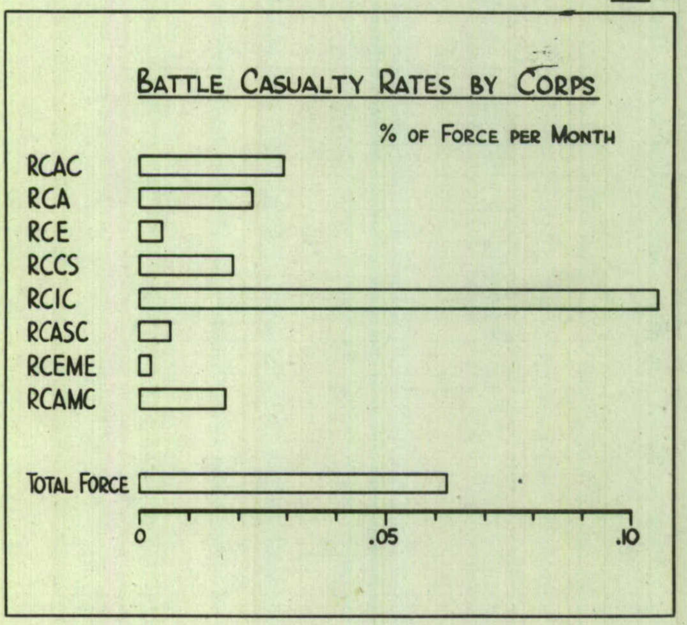


FIG 6

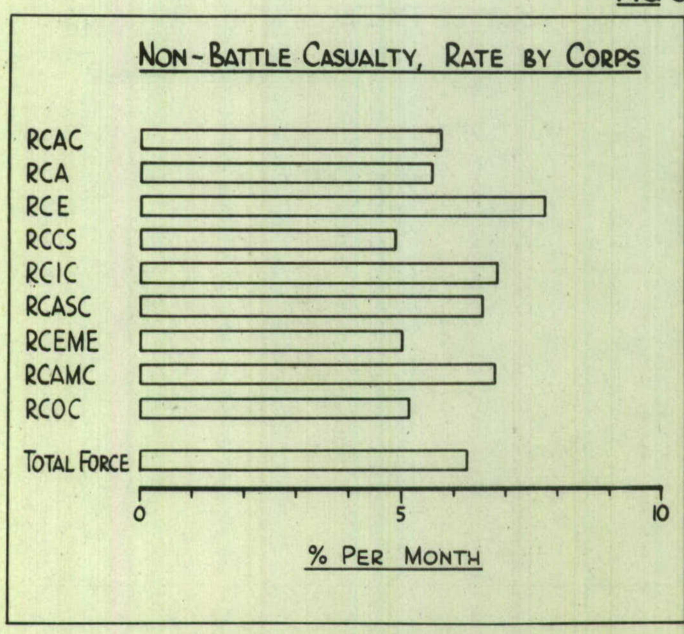


FIG. 7

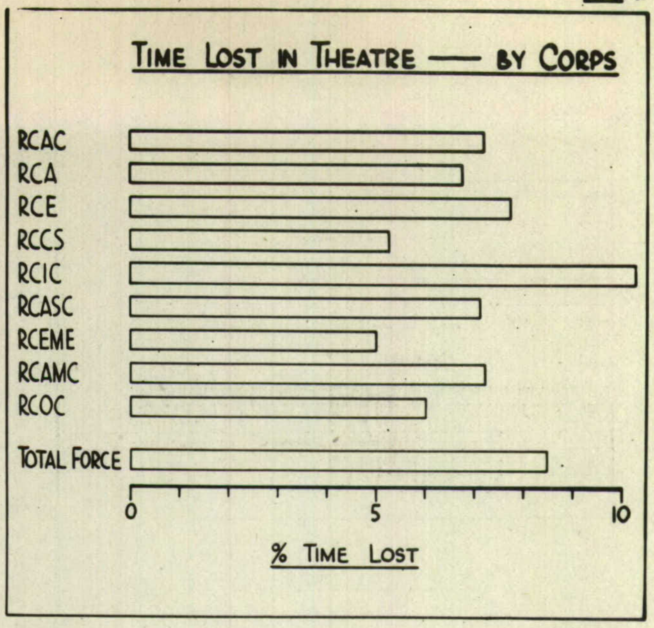


FIG. 8.

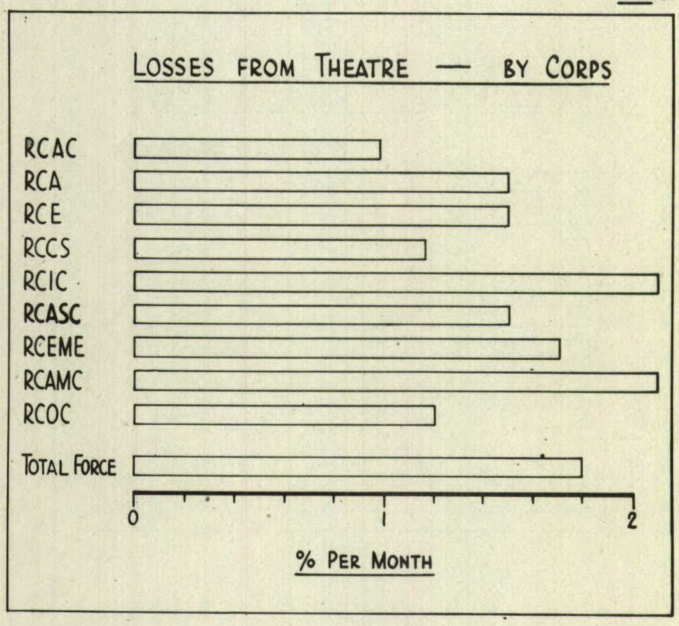


FIG. 9.

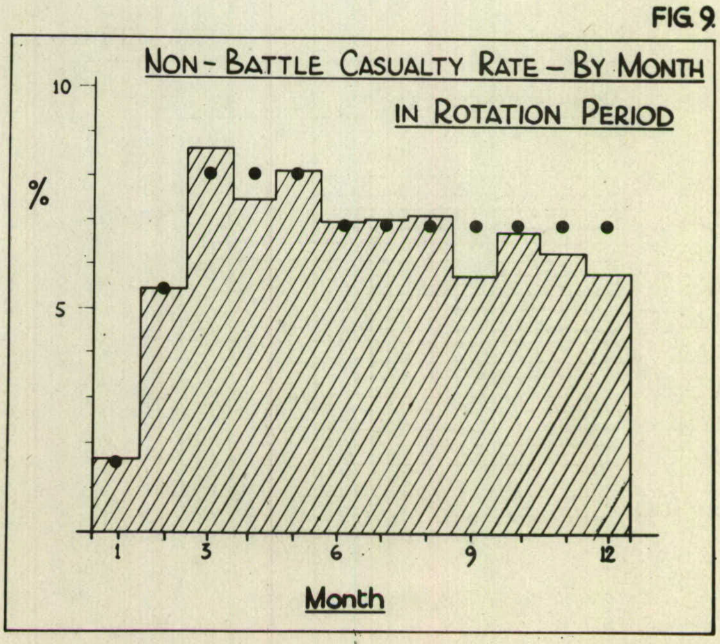


FIG. 10

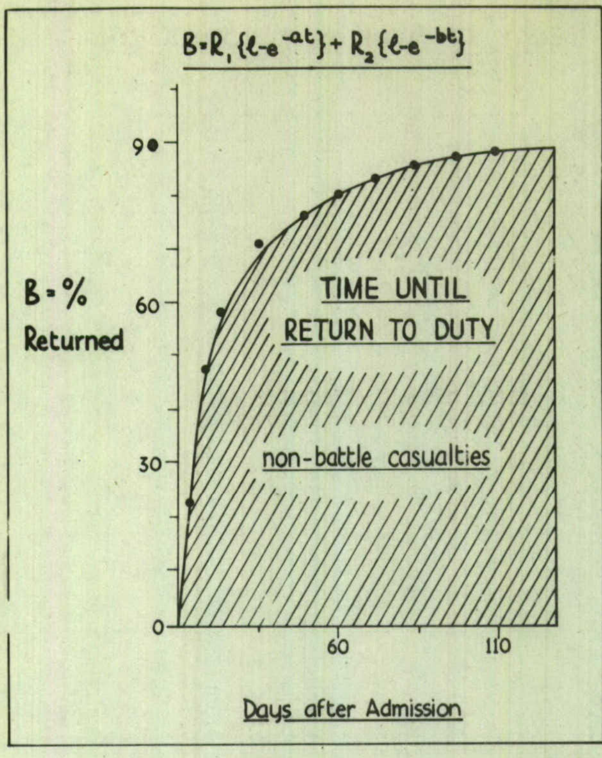


FIG. 11

RETURN TO DUTY FROM HOSPITAL

$$B = R_1\left(1-e^{-at}\right) + R_2\left(1-e^{-bt}\right)$$

B IS FRACTION OF HOSPITAL ADMISSIONS RETURNED TO DUTY

t IS TIME IN DAYS AFTER ADMISSION TO HOSPITAL.

EXPERIENCE	R_1	a	R_2	b
KOREAN CDN NON - BATTLE	·45	·0262	·37	·184
KOREAN CDN BATTLE	·62	·0272	0	-
E.J.O. WW II US NON-BATTLE	·48	·0415	·46	·123
E.J.O. WW II US BATTLE	·68	·0223	0	-
CIVILIAN POP. UK WINTER 43-44	·82	·0713	·18	-
CIVILIAN POP. UK SUMMER 44	·81	·0238	·19	-

FIG. 12

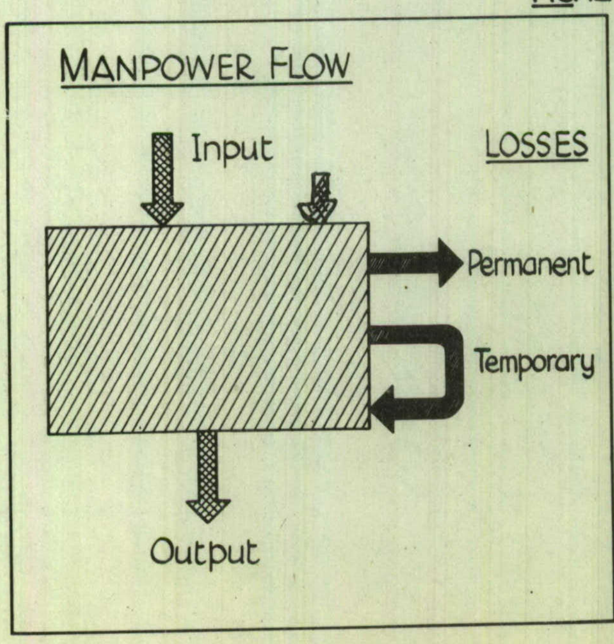


FIG. 13.

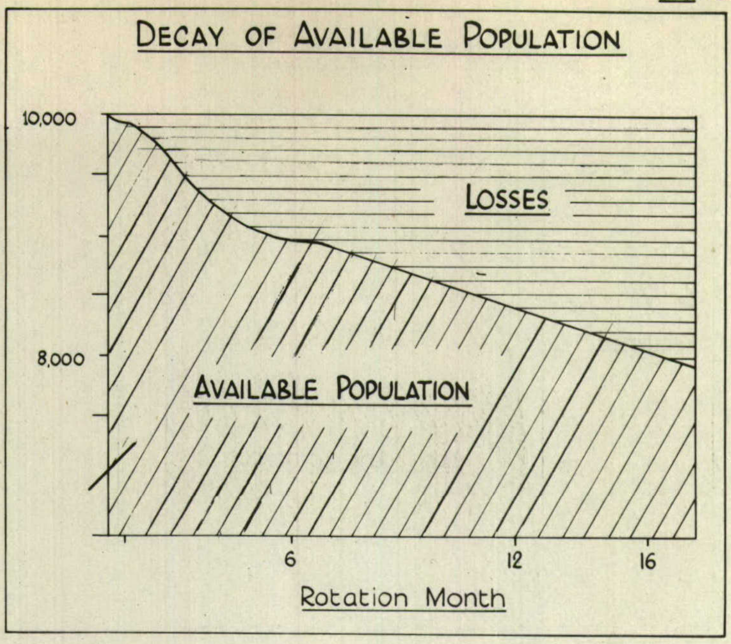


FIG. 14.

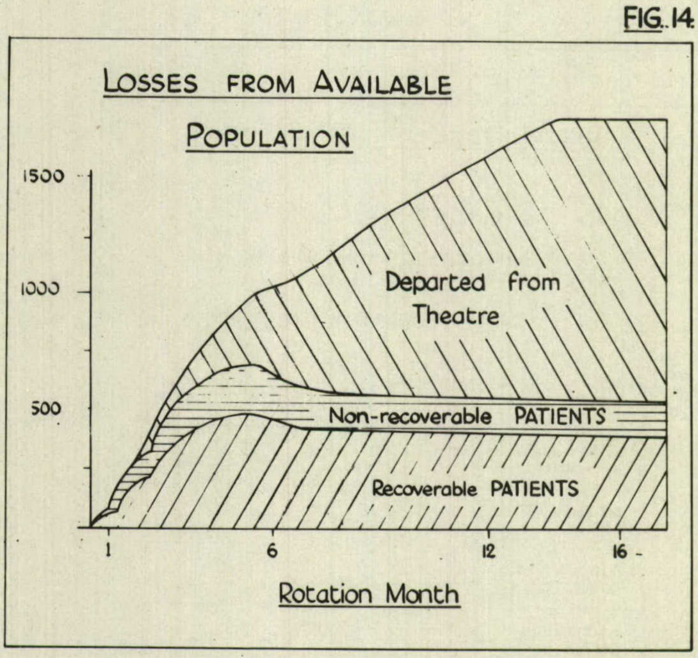


FIG. 15.

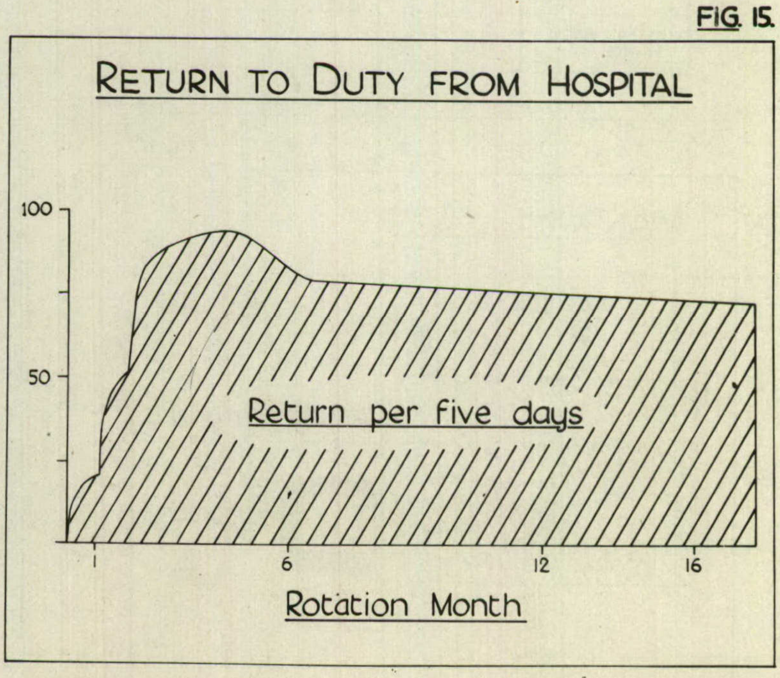


FIG. 16.

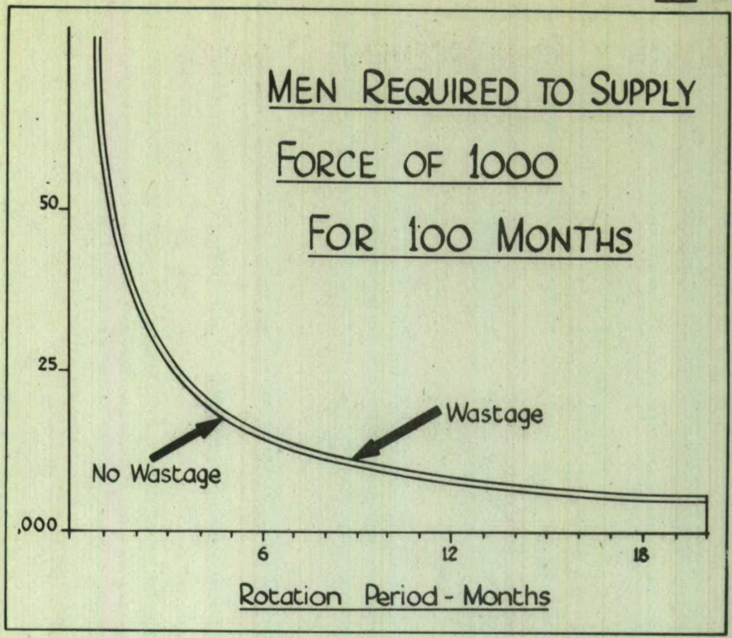


FIG. 17.

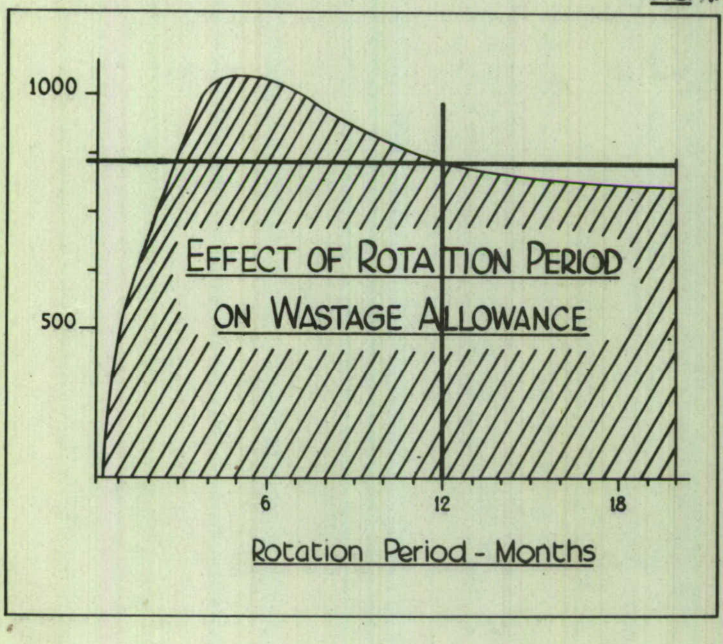


FIG. 18.

Three Possible Rotation Schemes

Scheme No.	Unit Rotation	Individual Rotation	When Reinforced
1	Yes	No	On Rotation
2	Yes	Yes	Monthly
3	No	Yes	Monthly

FIG. 19.

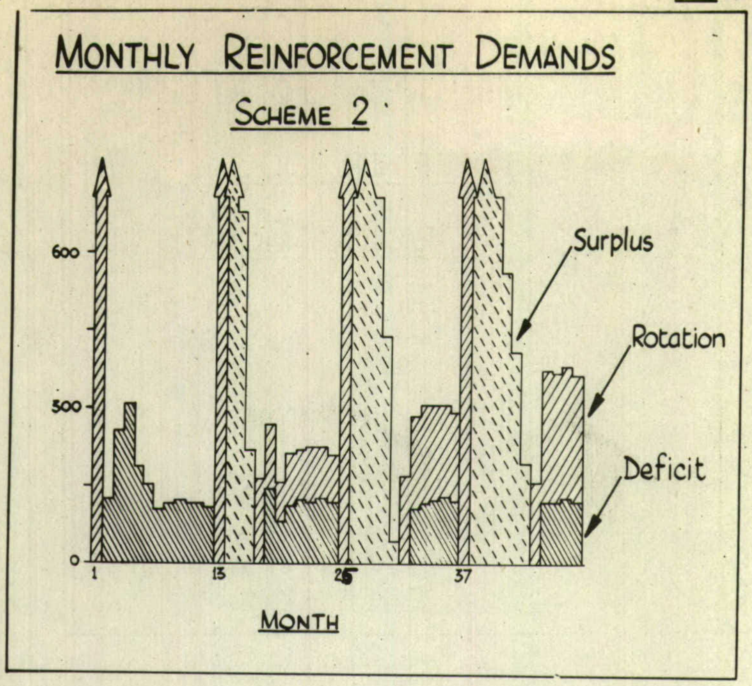


FIG. 20.

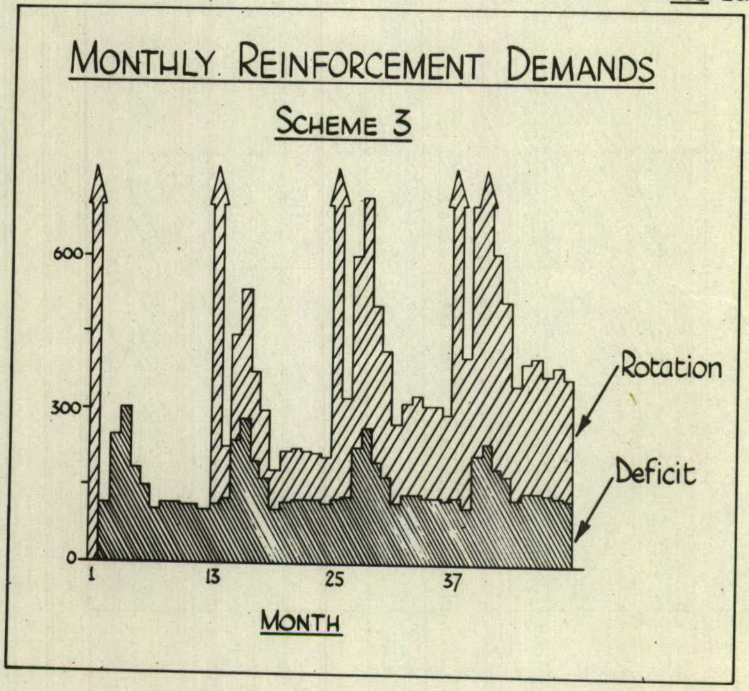


FIG. 21.

COMPARISON OF ROTATION SCHEMES

SCHEME No.	1	2	3	DIFFERENCE 2 & 3
AVERAGE MONTHLY DEFICIT	1,036	100	155	-55
SURPLUS-MONTHS IN 4 YRS.	0	14	0	2 SAFER
COST - 1ST YR. (No. OF MEN SUPPLIED)	10,000	11,689	11,689	0
2ND. YEAR	10,000	11,633	11,590	43
3RD. YEAR	10,000	11,601	11,507	94
4TH. YEAR	10,000	11,581	11,434	147
TOTAL COST FOR 4 YEARS	40,000	46,504	46,220	284
RESERVE AT END OF 4TH. YEAR. (MAN MONTHS SERVICE)	0	13,028	24,653	- 11,625 = 1,065 MEN SUPPLIED

THE OPERATIONAL RESEARCH SECTION IN MALAYA

(Presented by Lt.-Col. C. R. Nicholls)

This paper deals with the first year of the Operational Research Section in Malaya. It does not cover the psychological field, because that was dealt with by a separate section, formed later on. It is a personal paper, and most of the opinions I express will be my own and they are not necessarily shared, either by the Scientific Adviser or by the authorities in Malaya.

For ease, I shall refer to the Communist terrorists as 'bandits' though the importance of their correct title of Communist terrorists is, I think, fairly obvious. Similarly I shall refer to His Excellency, the High Commissioner, General Sir Gerald Templer as H.E. It is the way he is known out there: H.E. of course, standing for His Excellency, though it is probably not entirely without significance that it also stands for 'high explosive'.

Much of the paper will be devoted to the background of the emergency, and from those of you who know Malaya I would ask forbearance, but unless you know the background, I do not think you can appreciate the problems involved. Now for the background.

The country itself, physically, is about the size of England, less Wales, or slightly smaller than the state of New York. Four fifths of it is covered in jungle of one sort or another. The main physical feature is the main range, which runs down it rather like a spine, height ranging from six to seven thousand feet at its highest points. The climate - it's not a steaming jungle hell, but I think it's a trying climate, 85 - 90 degrees, steadily, year in, year out, and a very high degree of humidity. It's not conducive to great physical effort, and I don't think it helps people's brains either. It's most noticeable if someone has been out there for a long time that he starts suffering from an appalling loss of memory, and you will frequently find the person who just starts introducing someone and then clean forgets his name.

Commerce - rubber and tin, as you know, are the main commodities, with pineapple, coconuts, etc., subsidiary. Just a word on rubber - there are three million acres of rubber in Malaya, that is about the equivalent of Devon, Cornwall and Somerset, just solid rubber, and, in fact, it constitutes the bulk of the one-fifth which is not jungle. It's important, I think, tactically because a great deal of contacts take place in or on the fringes of the rubber. In fact, about 40% of patrol contacts take place in rubber. For those of you who haven't seen rubber, the tree itself is not particularly impressive. It's rather like a cross between a birch tree and a beech tree. Planting is in rows, about ten yards between rows and probably five yards between trees. They are either planted just absolutely straight in rows running right across the country, or else contour planted, and tactically, of course, there's a big difference between the two. Your visibility is much cut off if it's contour planted.

Population - about five million, roughly half Malays and half Chinese, with a scattering of Tamils and Sikhs, and also a certain number of aborigines, small in number, about 80 thousand, though estimates vary a lot, but extremely important tactically, as you can see. They live most of their time in the jungle, and many of them are fairly mobile.

The political set-up I won't go into in detail. You must, I'm sure, know it. There are nine states and two settlements, each with a great deal of discretion in their own internal affairs, and superimposed above that is the Federal Government. It's a difficult situation, I think, in which to run an emergency.

Adjoining Malaya you've got in the North, Siam, geographically very similar to Malaya, I think, helping as much as they can, but not of a very high standard of efficiency. To the South, Singapore, very much tied to Malaya, both politically, economically and geographically, separated as it is by the Straits of Johore, about 600 yards wide. Population - mainly Chinese,

and on the whole extremely wealthy, and there are many who think that a great deal of bandit funds come from the rich Chinese in Singapore. I think I'm right in saying this has neither been proved nor disproved.

So much for the country. A very brief background to the emergency. There was a Communist party in Malaya before the last war, and when the Japanese invasion started, the Communists were allowed to form themselves into armed bodies, and most of them finished as 'stay behind' parties doing guerilla tactics against the Japanese, and they became known as the Malayan Anti-Japanese People's Army. Another important thing from the point of view of the emergency happened at the time of the Japanese occupation. Owing to shortage of food stuffs, a great number of townsfolk were pushed out into the country and told to fend for themselves, and feed themselves, and they became squatters, squatting in the jungle on the fringes. They were naturally supporters of the M.A.J.P.A. both morally and physically, so by the time the Japanese occupation had ended, the seeds of the emergency had been well and truly sown. You had a trained guerilla force and you had the squatters with a strong communist sympathy, ready to support them. At the end of the war, the M.A.J.P.A. was disbanded and disarmed, but only partly disarmed. The Communist party tried to obtain power by semi-orthodox means, and when this failed in June 1948, they resorted to force of arms with a strength of between five to six thousand armed men, mostly ex-M.A.J.P.A.

Now, just a word on the bandit set-up. In its simplest form you can divide it into two parts. One which is called the Menyuen, and the other which goes by the slightly grandiose title of Malayan Republic Liberation Army. The Menyuen is the administrative side of the house. It does most of the clearing of messages, providing food and so forth, and the M.R.L.A. is the fighting element. The organization, I think, is a typical Communist one, it starts at the lowest level with the cell, then gets up to the branch, the district, then at that level you start getting all the ingredients. You have their propaganda chaps and you probably have a platoon of the M.R.L.A. tacked on. Above that, the state and the regional committees, and at the top, the central executive committee. Five men - Secretary (General Chong Fen), propaganda member and one representative from each of the three regions.

The bandits, as I said, have five main problems. The first is communications, part of that is done by ordinary posts and the balance is done by couriers, working on what one would describe as the closed system. That is, the courier takes the message from A to B, and at B he pops it in a letter-box which is in a tree or under a bush and it is taken on by a courier whom he doesn't see, and whose destination he doesn't know. From their point of view it has many advantages - it's extremely difficult to follow a courier line. The disadvantage from his point of view is that you can tap into it and start inserting your own stuff into it.

Weapons - I'm ashamed to say the bandits are very largely self-supporting. That is, what they lose to us they make good by recaptures. As far as is known there is no big influx of arms from outside. There is a small trickle, that is known, but it's very small, and before one condemns this business of loss of Security Force arms, I think you've got to realise how many people are under arms in Malaya, and we'll come up with that later. The figure, I think, is rather staggering. There are innumerable small isolated posts, miles away from anywhere, and I think the bandits would be very lacking in initiative if they couldn't, in fact, maintain themselves with arms.

Food is a very real problem and has been made more difficult by the introduction of extremely severe food measures. I think food control has probably now reached its limit and is extremely strict. But even so, you're faced with five thousand people trying to live off a population of five millions, and it doesn't require very much rice concealed in pockets, envelopes or even in their mouths, being smuggled to and fro to keep that party going. Vegetables are slightly more difficult; they are essential and they are bulky. It is easy to conceal rice, but it is not very easy to conceal cabbage, and bandits are now being forced more and more to grow their own food stuffs, and to grow it deep in the jungle. It's a very healthy sign, I think; bandit cultivation in the jungle is a very nice pointer.

Recruits - they are largely self-supporting at the lower level. As far as we know, there is no big central recruiting organization which trains recruits and drafts them out to their various sub-units. Recruits are normally taken in rather by subterfuge, the man who supplies food under duress is approached by the Menyuen, who say that the police know that you are supplying food, your only hope is to come in the jungle with us. Once in, he gets more and more embroiled in the Communist net.

Information is their fifth problem, and in this they are very well served. They have the Menyuen, which is a highly paid organization and a very good intelligence network. Slightly further in are the tappers. I do not suggest that the tappers are in any way disloyal, but through force of circumstance, I think they are bound to be a source of intelligence. They work in extremely remote areas and when a bandit appears from the jungle and holds a knife at the tapper's throat and says "What do you know?", it's difficult, I think, to blame the tapper passing on a certain amount of information.

And deeper, beyond the tappers, you've got the aborigines, again in many cases probably under duress. Our target in the bandit world is an interesting one, I think. It's rather nebulous. Concentrations, on the whole, are rare; you do get parties of 100, 150 occasionally, particularly in Johore, but they are the exception, and the normal party is the small party of three or four men, moving possibly to collect food, to collect information, to collect money or on the move giving propaganda talks. If you are lucky you may meet a party out on an operation, and that's about the only time you'll meet a large party.

Bandits work out at roughly one per ten square miles. If you picture ten square miles in Malaya, it's quite a sobering thought. One might think the state committee or something like that would offer a good target, but one's got to realize that all these things, the branch, the district, the state and everything else are not permanent bodies. They meet now and again. The state committee probably meets once every six months, somewhere fairly deep in the jungle. The members that are meeting probably don't know where they're going to when they start off, they're merely led by couriers to a central meeting, then the meeting breaks up and disappears.

Dress doesn't help one much in identifying the target. The M.R.L.A. are usually uniformed, but it may be khaki, it may be jungle green. They may be dressed as tappers, or they may, as they have frequently been seen, be dressed as policemen.

Nationality is a slight guide. The majority of bandits are Chinese, but there are Malays and there are Indians, so that one has got this rather nebulous target, sitting behind a very unpleasant intelligence screen, and that is a problem.

I think you can divide our own set-up into two very clear phases, which I described as the Gurney phase and the Templer phase. The Gurney phase got off, as I think any emergency is bound to do, to a shaky start. There were very few troops on the ground, Intelligence was not organized for that sort of thing naturally, and it saw the steady build up of security forces in Malaya up to its total of 22 infantry battalions or a total of 40,000 men, army, navy, and air force. The police, who are always armed, expanded to 60,000, so there were 100,000 regular people under arms, and behind that the Home Guard, 200,000, not all armed individually, but all capable of carrying arms and working on a full basis. So there are quite a lot of weapons available to the bandits to go for. The other big thing of the Gurney phase was the appointment of a Director of Operations, the late General Briggs. It was a peculiar position, he had no executive power whatever. Everything which he achieved he did by persuasion, and there are two outstanding things which he did. The first one was to tackle the problem of squatters. There were half a million squatters in Malaya at the start of the emergency, and he tackled their resettlement, drawing them all in and regrouping them into the new villages, which was undoubtedly a very hard blow to the bandits.

The second important thing, I think, was his sponsoring of the things called 'Swex' and 'Dwex' - State War Executive Committee, and District War Executive

Committee. I'll deal with 'Dwex', 'Swex' meant the same thing, only bigger.

The 'Dwex' consists of the MCS officer in the district, the senior Police Officers, and the senior army officer, probably a battalion commander, and whilst the operation plans are probably produced higher up, the final details of working out is normally done by the 'Dwex'. It sounds extraordinary that the war should be run by committees and lots of people think it odd at first sight, but when you get down to it, it's apparent it is the only way it could work. Every problem you touch at that level has the three ingredients in it. Consider the battalion commander who wants to lay on a surfew, a special operation. The legislation of it is a civil affair, carrying it out is a military one. Take food control. Again the same things are mixed up. If you want to bomb near the rubber you've got to move the tappers; the same thing again, and it's absolutely basic, that practically every problem in Malaya involves those three ingredients.

The Gurney phase ended with the death of Sir Henry Gurney in an ambush on the road to Fraser's Hill. A period of rather low morale, I think, followed that. Then the visit of Sir Oliver Lyttleton, and then the arrival of General Templer, with the effect of several atomic bombs on Malaya. He produced straight away three very big changes. The first was that the post of High Commissioner was merged with that of Director of Operations - one man. Second was that as Director of Operations, he assumed complete and direct operational control of all security forces in Malaya, Army, Navy, Air Force, Police, and Home Guard.

And the third big point was his enunciation of the view that in the war against communism, the shooting war represents only 25%, and 75% is the battle for the hearts and minds of the people. The analogy was drawn between fighting communism and fighting malaria, in that it is no use merely swatting mosquitoes - shooting war - unless you stamp out their breeding ground. Now I don't say that was a new conception, but the implementation of the policy in that direction was certainly new.

There was a fourth point which H.E. brought, and that was that he was extremely research minded. He was surprised there was no Research Section actually in Malaya itself, though there was one, of course with GHQ, in FARELF, but not able to devote full time to the problems in Malaya. So he reorganized his small staff in three sections. There was a co-ordination section which had MCS, Army and Police three ingredients again at major level. There was the planning section - same ingredients again plus the RAF at grade one level, and finally the Research Section designed to have the same ingredients, though it didn't, in fact, quite work out like that. It's a point of interest, I think, that Research staff was tacked on to Director of Operations staff, and not, as is customary, probably on to the nearest military headquarters, which would have been headquarters in Malaya. I think the reason was that they obviously had to deal with both civil and military as well as the Police, and the only way they could do it efficiently was from that level. Similarly, they had to be completely impartial between those three ingredients, and that could best be done from impartial headquarters above.

H.E. was extremely impatient to start the Research Section and he was not prepared to wait for war establishments to be drawn up and people to come out from home. He said he would take someone from the theatre, not necessarily research trained, and get the thing going, rather than wait. So I was whipped out from doing G.1 staff duties at GHQ FARELF and sent up to Malaya, and I started with two tremendous advantages. First, that the section obviously had the complete backing of H.E. right from the start. It was a very big thing. The second one was that I had at least been dealing with problems in Malaya, although from the GHQ end, for some time, and I know most of the brigade and battalion commanders and I think that is a great help. Whether one likes it or not, there is no doubt that research in the minds of the individual officer in a fighting unit is slightly suspect, and it was a great help to me that I had at least met them on more normal occasions before, before starting research.

The tasks given to the section were really threefold. The first was the evaluation of new ideas, the next one was a series of special studies which have

come from time to time from H.E. himself, and the third was the analysis of operations to assess success and failure of different tactical measures and to relate them, if possible, to the effort involved.

I started the first two months completely solo, and then the Army reinforcements started arriving. I received a Private RASC, my clerk - a plumber in civilian life - followed by another Private RASC who was a linoleum designer. I had an officer attached for a short time before he went sick and then I had a police officer, so, by and large, it's a one-man-band, which is, I think, an extremely dangerous thing for a Research Section.

New ideas flowed in to H.E. from all over the world, from all classes of people. Most of the suggestions had one thing in common: how to finish the emergency. Where they differed was the amount of time they allowed for it. Some allowed a week, some even went as far as two or three months, and some produced schemes to last a year. They had to be considered carefully, because whilst they may have appeared stupid at the time, conditions might have changed and made them possible. The special studies themselves came down from H.E. in minute form typed, as his notes are, in bright red, signed in scarlet and written in very refreshingly un-minute-like language. These were extremely clear, straight to the point, normally with a line at the bottom, saying "Answer privately within three days" or seven days, or whatever it was. The sort of things that came down were "We seem to be finding an awful lot of bandit food dumps and destroying them - why? - surely there's something else we can do. It's the nearest contact in many cases we make to the bandits at all. Can't we booby-trap them? Can't we use lie-detectors? What about the size of bandit camps? We always hear that there are no large parties of bandits and yet we hear reports of camps for 100, camps for 150, camps for 200. Are our estimates wrong, or is the appreciation wrong? Is food control really successful? We're finding just as many food dumps as we ever did. Is it that the food dumps are old ones which haven't been found before, or are they with fresh contents? Can't we have some scheme whereby a simple patrol commander can assess the age of the contents that have been in the food dump?" That sort of thing. All things which everyone kicks themselves for not having thought of before.

Analysis of operations was undoubtedly the biggest of the three tasks, the main problem being that there was absolutely no data whatever on which to base an analysis. The only data in Malaya was that contained in sitreps sent back to the Colonial Office and War Office, which merely gave the number of bandits killed, how many arms captured, how many contacts and so forth. Before we could start on this, we had to make arrangements for the supply of data, and we produced a simple form called forms ZZ to be filled up every time security forces contacted bandits. It asks the questions one is expected to ask - "What is the size of our own party, its composition, what are its weapons? What is its formation at the time of contact? What range? What type of country? What time of day?" and so forth. It had to have attached to it a narrative and sketch. Form ZZ, or the mention of it, produced, as one might expect, the most violent opposition. Everyone raised their hands in horror and threatened that the whole emergency would come to a grinding halt, because people would be so busy filling in forms. A little examination showed that, in fact, the number of contacts in Malaya are so few that a company commander would be doing extraordinarily well if he had to fill in one of these forms per month, and we reckoned that it wasn't an insuperable load for a company commander, because he presumably in any case debriefed his patrol very fully when it finished and he ought to have asked all the questions on this paper. I don't think the form was perfect, and I don't think it would have been if we'd spent longer on it, but it at least had the merit of speed.

The section formed on 4th April, and this form was cleared by the G.O.C., by the Commissioner of Police, and was being filled in by the troops on the ground on 1st May, so it went fairly fast. There are two important points in the form. The first one is the narrative. I think the narrative is absolutely essential, and without it you just cannot get the feel of what is going on. I don't think you can do it from a cold proforma, and secondly, unless you've got the narrative, you can't start screening your proforma and removing, for example, those which obviously had covering fire, which were a running engagement, or

rejecting those which weren't a straight ambush followed up afterwards by patrol contact. So, the narrative, I think, is important.

The only other point about it was that it was to come to us direct from the unit, and no copies were to be made by Brigades, District, or anyone else. The object of that being that it should be a really honest account and that no-one will be taken to task for relating the most gruesome details if some frightful engagement had taken place. And people were, I think, extraordinarily honest with their forms. We used to get some accounts which really would make your hair stand on end, giving, one after the other, a series of most dreadful faults, which, I think, says an awful lot for units. They work fair, they play fair, and write the truth.

Well, having launched the form, we then - I think probably very rashly - the temptation was strong - did a first review on one month's forms, and although it's rash, we did get something out of it. Three points emerged straight off, after merely one month. Firstly all these fearful ambushes which were taking place at the time with the Security Forces, were taking place on parties who were moving in single file, every single one of them, and, in the majority of cases, they were following up after an incident, so some pretty strong instructions went out on that.

The second point to emerge was that of all the vehicles being ambushed on the roads, the Police armoured vehicle was the most popular target, that is the armoured personnel carrier of the G.M.C. Not only the most popular, but it was also receiving a pretty high casualty rate in personnel. The army who were also using the same vehicles, were nothing like as popular a target and were getting practically no casualties, so that was gone into and from that emerged the fact that the police, in fact, had not got a really tight ambush drill, or a loading drill.

The third point that emerged was that although ambushes were responsible for killing more bandits than any other type of operation, on our side they were highly unsuccessful. Only 50% killed by bandits, so that the follow on from the first review was, I think, quite obviously a pretty good dig into what was going on in the ambushes, and we waited for our month's data and then started on that. I won't go through in detail, but I will mention some of the headings we took. The first one was "Can we sort out what is the real difference between an ambush laid on information and one laid on no information; that is, someone's hunch that there's a good place here to lay an ambush!" Well, we found the difference was pretty remarkable. Ambushes on information were being sprung one in ten, on no information one in a hundred, and, in fact, 58,000 ambush hours, that's not man-hours, that's ambush hours, were spent on no information to achieve 15 kills. We examined the country to see if the country made much difference. Was it better to ambush in rubber, jungle or heather? Then the lay-out. Was there any difference in layout? We found there was. There were three types of layout in use, and one was killing almost exactly twice as many as the other two types. We checked the length of the ambush. Was the length of ambush too short - was that why we were getting such bad results as against the length of the column of bandits expected to go into it? We found it was not. The ambushes, on the whole, were quite deep enough to contain the entire bandit party, but they were being sprung at the wrong moment. We did a check through on weapons to see which weapon we thought was best in the ambush, we studied range, day of the week, day of the month, hour of the day, everything else, any particular time when ambushes were more likely to be sprung. We found that there were two periods of the day which contained the peak number of ambushes. We compared night and day - was there any great difference? There obviously was a very great difference in range, but from the success point of view, there was practically nothing in it, which required further examination.

We considered the time for preparation. Were people settling into ambush position at the last moment, or had they normally got a reasonable margin of time to settle in? We found that 75% had half an hour to spare. And lastly, we considered the bandit ambushes. Had they got something which we had not, and we found, contrary to popular opinion, that bandit ambushes were no better than our own. In fact, they were worse. There were one or two startling

ones which obviously got headlines, but they were not due to any super technique in ambush laying. They were, in almost every case, due to a very serious fault in Security Force tactics.

We then did a series of three monthly reviews, trying to see if there was any difference in trend. Whether patrols were getting better or worse, whether ambushes were coming up on top, whether there was more stuff by night than by day, and so forth. We asked units to fill in forms giving details of operations in which there was no contact. We found, without that, that you were merely getting the contact side of it, and not what effort was being expended for nothing. It was worth doing, I think. We did a patrol paper on the lines of the ambush paper, and lastly, we did a paper on bandit camps, I think probably the most important, though not really complete.

We felt that there must be some guiding rules to siting a bandit camp and if only one could get their rough rule of thumb instead of searching the whole of an area for camps, we might be able to eliminate certain areas, and we studied this question. We tried to examine their protective layouts and see whether they have certain standard rules, and we found they had. We examined present methods of attack to see which were paying and which weren't.

A very short word on the reports we wrote. I think they're different from most Operational Research reports because they were aimed at a different target. H.E. was very clear that the Research Section in Malaya existed primarily to help troops engaged in the emergency. There were not the staffs on the G side out there to re-write Operational Research reports in language which could be understood by the company commander, so that all reports were written in the form to go straight down to the company commander, and I don't mind admitting that before any of them went out, I used to send them in draft to three battalion commanders and say, "Is this clear? If it's not, I guarantee I'll rewrite it. I would also like your views on whether you agree, but I won't guarantee to alter it if you don't".

So much for the research side. Now from that has emerged, I think, a number of major points. Their importance lies in the fact that though some of them may be influenced by the peculiar conditions in Malaya, in general, I think, they are applicable to a cold war almost any where. As I haven't got time to do the lot, I'll take two. The first one is rarity of contact, and I'd like to quote figures here. On the average, it takes 600 hours patrolling before you get a contact. That's not man hours, it's 600 patrol hours, and that's not to get a kill, it's to get a contact, even a sight of bandits. In ambush on information, an ambush party, on the average, has to do 130 hours sitting in the ambush position, extremely uncomfortable, probably being bitten to bits, before they get a kill. In an ambush on no information, they have to spend 3,900 hours. On the average, the Army in any one month in Malaya only spring 32 ambushes. You'll see there are 22 battalions, so that a battalion is doing fairly well if it springs two ambushes in a month, and there are five, I think, extremely important results from this. The first one is a research worry pure and simple. This rarity of contact does handicap analysis very seriously. You've got to go on for a very long time before you get enough cases to start really breaking down into detail and the danger is that during that period, there has been some tactical change.

The second one sounds like heresy, but I believe it to be true, and that is that the man on the ground in Malaya, and by on the ground, I mean right low down, is not really the best judge of tactical doctrine. If you talk to commanders you'll find that they all have the most decided views, quite rightly, on things like ambushes, and they'll say - "This is the way we always do our ambushes, this is the way it works, we've found out just the way to do it", and when you ask him how many have actually been sprung, you'll find that he probably only sprung two or three in the whole of his time out there, and I don't think you can judge tactical doctrine on three cases.

The third point arises really from the same thing, and that is that unless there's some form of selection in ambush parties going out, I don't believe you'll ever get the best results. I know this is highly controversial, but if, as a battalion commander you say, "I will have no selection, every section will

go out in turn", then in that case the section will spring an ambush, if it's a lucky battalion that's doing well in the ambushing, once every 18 months, and I don't believe you'll ever get good operational experience on that basis, and I think in ambushes of all things, operational experience is the really important thing. It is really terribly difficult to simulate through training the tenseness of the moment when you spring an ambush. Now there are, I know, arguments against, one hears the cries of "Specialists," "Gladiators", ambushing being a normal infantry task, and so forth, but for or against some sort of selection, I think you've got to consider certain facts, and they are these.

At the moment we are only killing one out of every four bandits who are involved in a security force ambush. We are losing in fact 100 bandits a month, and we're only at the moment eliminating about 100 a month by all means, patrols, ambushes, surrenders, captures and everything else. If you examine the failures you'll find a large proportion are undoubtedly due to inexperience. Thirdly, the ambush on good information is probably the result of at least six months' extremely hard work by a very large number of people in Special Branch, and if that ambush fails, not only has that work been wasted, but quite a number of informers are probably compromised and may well lose their life. And, I think one wants to ask oneself whether the ambush really is a normal infantry operation. Personally, I don't think it is. I think the good ambush is just pure cold blooded murder, carried out best by people who are prepared to sit for hours and hours and hours merely for the joy of killing at very close range, and I don't think that characteristic is necessary for the normal fighting soldier.

The fourth result of this rarity of contact is the effect on special devices. There have been many suggestions for the use of what I describe as special devices - infra-red, sniperscope, microphones, listening devices, vibration equipment - all those sort of things. Well now, if you are to have this equipment in the right place at the right time, you have got to have it in very large numbers, and if you're going to have it in such large numbers, I don't believe you'll ever have enough specialists to send with each piece of equipment. If you can't send a specialist, then the equipment has got to be simple, it's got to be used by the normal infantry man. It's got to be equally capable of use by a Gurkha, an African, Fiji, a Malay, or Malay policeman, so it's got to be pretty simple. Secondly, certainly as far as stuff which goes on patrol, it's got to be carried for a long time before it goes into use, so it must be (a) light, and (b) extraordinarily robust, otherwise when the time comes, it will not work.

And the fifth point which comes with rarity of contact, is that of alertness. It's easy, I think, to condemn the low results of patrols in Malaya. Before condemning these low results ask yourself how you would feel after, say, tramping around for 600 hours in a most unpleasant bog snipe shooting without seeing a sign of a snipe. Would you really, with a split second contact, then get a kill? I think it's one of the big problems in Malaya, how to get people just before contact really balanced and ready for it, and I must admit, I have no suggestion to offer. We have been trying dogs, and dogs at first looked like being the answer, but I personally begin to have doubts whether they are.

So much for the rarity of contact. The other point is the main operational problems which, I think, one wants to get clear. They are to my mind three, and they come in this order. The first one is to locate the bandits, because unless you locate them, you can't kill them, at least not efficiently. You can do it by taking on a great area target, but it's not efficient, and if you can't locate them, you're playing blind man's buff. Now I would agree that location is primarily a matter for intelligence, but any scientific aid which can be given to the detection or location of bandit camps, or indeed, small bodies moving in the jungle, I think, is of the highest importance. Having located them, you've got to get them before they move, and to do that, you've got to get through, over, or round or under this frightful intelligence screen, and that's a very real problem. Ruse and guile go quite a long way, but I don't think they go the whole way, and, at the moment, the S55 helicopter is undoubtedly going a very long way towards meeting that requirement.

Lastly, having located them, having got them before they've moved, you're going to face the killing. Well, that, I think, is by and large an orthodox problem, but there are these two factors in Malaya. The first is terrain. They've only got to move a very short distance before they're under cover. The second is, they're not seeking contact, their chief desire is to get away, so that your time of contact is desperately short, if you are going to get a high proportion of bandits, you have to kill quickly.

Finally, I feel no talk on Operational Research in Malaya would be complete without some tribute even from this very low level, to that great driving force behind the whole of the emergency, its every aspect, His Excellency the High Commissioner, General Sir Gerald Templer. Any contribution to research that has come out of Malaya is, I think, the direct result of his interest in all matters of research, his tremendous backing both to the Research Section on the operations side, and psychological warfare; and his sympathy, never too busy to discuss things in the greatest detail. And lastly, his crystal clear directions.

RESTRICTED

Trends in Warfare

Present: Mr. A. W. Ross, U.K. Chairman

Canada

Dr. A. C. Lauriston

U.S.A.

Dr. H. Cole

Miss G. Donovan

Dr. G. Gamow

Lt.-Col. H. E. Gould

Dr. J. S. Green

Dr. L. Hawkins

Mr. B. Marshall

Brig.-Gen. S. L. A. Marshall

Lt.-Col. D. E. Munson

Col. E. M. Parker

Dr. E. Paxson

Dr. M. Vigneras

U.K.

Mr. C. L. Barham

Mr. E. Benn

Mr. S. W. Coppock

Mr. R. W. James

Maj. M. P. King

Mr. J. D. Oates

Col. Rycroft

Mr. H. A. Sargeaunt

Mr. R. W. Shephard

Dr. I. J. Shaw

Mr. E. G. Smith

Brief for Discussion

Introduction

1. Operations Research in World War II was largely concerned with collecting information from recent operations, analysing it, and applying the lessons to (then) current operations in which it could be expected that the pattern of war would not be radically different. This was a valid process, justified by results. Current Operations Research in Korea and Malaya, and to some extent perhaps in Germany, is similar.

2. But most Operations Research now is concerned with the specification of optimum weapon systems, tactics etc for the NEXT war, which implies that we know what this war will be like, and the further ahead we are trying to plan, the less certain must we be of what we should be planning for.

3. This uncertainty also applies to the time scale. Perhaps it is satisfactory to proportion our effort between an immediate, intermediate and a distant threat (which at least fits in with the time scales of production, development and research) but these proportions should ideally be related to our estimates of the probability of a war as a function of time.

4. There have been claims that Operation Research is capable of supplying, by a scientific study of the problem, a more accurate assessment of requirements than has hitherto been achieved. If we are to justify these claims we must make sure that we solve the right problem, otherwise there is no particular merit in a quantitative solution merely because it appears precise. We must make our own assessment of the time-scale. Finally, we must not forget that most of the operational data which we use refers to the last war, often to the (particular) closing phase of the last war, except for Korea and Malaya which we should also consider as special cases; although it may be the best we have, this data decreases steadily in relevancy the further ahead we are trying to plan.

Determination of the Form of a Future War

5. Despite its interest and importance, this problem has received relatively little attention from scientists. It is obviously very difficult, and, as with all extrapolations, an element of uncertainty which increases with the prediction period must be expected. There would appear to be three main lines of approach:

(a) a study of trends in warfare based on historical data regarded as time series; alternatively hypotheses on the nature of the trends may be deduced logically or intuitively and validated against the available statistics; (in practice these two methods are equivalent)

(b) a study of the axioms of war, in which hypotheses or postulates concerning fundamental principles are again tested against the available statistics; and

(c) a study of the effects which current and envisaged weapon, economics and political developments can be expected to produce.

Trends in Warfare

6. The study of historical data as a time series presents considerable difficulties. Not only are major wars relatively infrequent so that the corresponding time series contain few terms, but the data is not particularly reliable and there is also often a discontinuity between successive terms corresponding to the introduction of new weapons or a change of emphasis in the weapon systems. This limits the method to the study of broad trends and gross effects.

7. Trends which have so far been determined include:-

(a) a general increase in the number of countries which become involved in a major war

(b) a general increase in the size of the opposing armies

(c) a general increase in the proportion of the population which is mobilised and which is engaged in war production

(d) a general increase in the expenditure on war, expressed as a proportion of the national income

(The above general increases hold up to the First World War, after which there is a tendency towards saturation)

(e) a general increase in fire-power and mobility

(f) a general decrease in the ability of an army to live off the country, or, alternatively, a general increase in its dependence on its own country for war production and food

(g) a partial change of purpose from the routing of the opposing army in combat to the destruction of its supplies or the occupation of its sources of war potential

(h) increasing attacks on the civil population

(i) a general increase in the length of front defended and in the depth of the defences

(j) a reduction in the linear and area density of troops on the ground

(k) an increase in the protection afforded to the defending troops

(l) an increase in the range at which casualties are produced, and, in particular an increase in the proportion of casualties produced by artillery

(m) an increase in the cost of inflicting a casualty

(n) an increase in the ratio of prisoners to other casualties

(o) a change in the composition of an army, towards fewer infantry with more artillery and greatly increased supply services; and

(p) a reduction in casualties and deaths due to disease.

A number of these trends are, of course, wholly or partially inter-related.

8. Obviously considerable care is called for in the interpretation and use of these broad trends. While the above list is interesting, and of course does not necessarily include all which can be extracted, it must be admitted that it does not paint a very detailed picture of a future war. In particular it tells us little about tactics, which presumably are too closely dependent on weapons, and also makes no mention of the time-scale, although this aspect has been considered by Richardson.

The Axioms of War

9. This approach assumes that there are certain unchanging axioms in warfare, related to the "Principles of War", which can be deduced logically or intuitively and validated against the available statistics. The reason for believing in the existence of such axioms presumably lies in the large part that the human element plays in warfare, which together with the constancy of human nature and endurance, suggest that some "operational constants" beloved of operational researchers may exist. At least such axioms have been advanced by military theorists from time to time and, even if they were not expressed numerically, have formed the basis of military plans. Presumably,

also, the timing of wars is related to the changing political and economic situation.

10. There is less difficulty in propounding possible axioms than in their subsequent validation. Among the difficulties encountered in validation are the shortage of reliable and complete statistics, the differing accounts and interpretations of the various actions and motives which exist, and the large number of factors involved so that each of the major battles and campaigns seems to be a special case peculiar unto itself.

11. Among the various hypotheses which have been advanced from time to time are included:-

(a) that there is a maximum casualty rate which an army or commander is prepared to accept

(b) that there is a minimum superiority ratio of forces required for success; and

(c) that the indirect approach is more successful and entails fewer casualties than a frontal attack.

12. Whilst there is probably an element of truth in these hypotheses, few, if any, can be regarded as validated in a strict statistical sense. It is now suggested that it is too much to expect constancy in the various parameters of interest since we cannot isolate any factor from the many others which undoubtedly influence the outcome to a greater or lesser extent. It is therefore likely to be more profitable to accept that each factor or parameter (such as the ratio of size of forces required for victory) is at best described by a distribution function rather than a constant, without necessarily trying to invoke some fundamental concept. Such a set of distribution functions would then provide a quantitative description or model of war into which the broad trends could be incorporated. It should, however, be appreciated that a full description would require a set of conditional probability distributions, and that this is not likely to be achieved except, possibly, for World War II.

Weapon Developments

13. Here, to determine the pattern of a future war, we can take a model of the last war described by a set of distribution functions, and use what would be the effect (in all its aspects) of likely weapon developments.

14. Alternatively we can adopt a more abstract "games theory approach" in which we consider weapon systems and deployments for each side (based, in the case of the enemy, on intelligence or our knowledge of general scientific and technical progress) and determine the most profitable strategies and tactics. Presumably, here, strategy includes the timing element, and the study should be extended to include political and economic factors. It does not, of course, follow that the enemy will use his best set of strategies and tactics, and our own set must be sufficiently flexible to permit of modifications by which we can profit from his inefficiency.

15. Both of these approaches are commonly employed, and, even if the analyses are neither quantitative nor complete, form the basis of most military appreciations.

Need for all approaches

16. The third method is capable of yielding the most specific answer, but, if it is used alone, there is a danger that we become obsessed with the importance of some particular weapon or political consideration and overlook the broad compensating factors. On the other hand it is unsafe to expect the trends in warfare to continue unmodified unless they are consistent with technical and economic developments. A study of the factors which affect an action, and the timing of a war, is necessary to the formulation of a quantitative model which can be applied to the study of specific problems. All three approaches should therefore be tried.

The Challenge

17. The problem of assessing the likelihood of war in the future, and the form which it would take, presents a challenge which Operations Research must meet. A review of progress and an exchange of ideas seems appropriate.

Discussion

1. The Chairman opened the discussion by pointing out that if Operational Research were to fulfil its aim of specifying optimum weapon systems and optimum tactics for the next war, it was necessary for uncertainties in the form and time scale of this war to be reduced as far as possible. He suggested that three main lines of approach could be used:-

(a) A study of trends of warfare based on historical data regarded as a time series

(b) A study of the axioms of war and an attempt to confirm them statistically

(c) A study of the effects which current and envisaged weapon, economic and political developments can be expected to produce.

2. Mr. Smith outlined some of the work which had been done at A.O.R.G. using the first of these methods and presented a series of graphs showing how factors such as size and cost of war, casualty rates, ammunition expenditure, fire power and range of engagements, and dispersion had altered over the last 250 years. It was agreed that the trends demonstrated could be of value in planning on a broad scale; it was, however, difficult to use this method to make a detailed estimate.

3. Dr. Gamow stated that since methods of trial and error could not be used in warfare, it was necessary to develop methods of pre-calculating results. He suggested that these might be achieved by using battle models and electronic computors, and gave examples of simple models he intended to try. The Chairman pointed out the difficulty of ensuring that when models were used, the picture was realistic with respect to the next war and that correct values were assumed for the parameters involved. Dr. Paxson said, regretfully, that he could not agree that a simple model would give a true answer. In warfare, many factors (such as, for example, a commander's decision) which could not be taken into account in a simple model, play an important part in determining results. He considered that it was necessary to introduce realities of this kind and therefore, that only an integrated war game played between military personnel could be of use. Colonel Parker agreed that in war a decision taken by a commander was of fundamental importance, but suggested that if one regarded war as a chain - decision - engagement - decision etc. - simple models could be of use in determining the outcome of the engagement stage. In this respect, Mr. Benn thought that the models might be of value in cutting down the time taken by Army manoeuvres. Other speakers were concerned at the great increase of time necessary to play a war game if it became too complex, and thought that it would be useful to check any results obtained against experience in past battles. Lt.-Col. Gould further suggested that electronic computors could well be made available to the Staff of higher commands, as he thought that far too frequently decisions were made without taking into account many factors that could well be fed into a machine. There was some disagreement with this sentiment, but it was thought that even if absolute values could not be obtained for many of the factors (e.g., morale) involved, a staff officer might find such a machine of value in determining how sensitive the result of the battle was likely to be to the various assumptions he had to make in coming to his decision.

4. Brig.-Gen. Marshall thought that there was need to extend the approach to cover the "Geometry of Tactics". He was convinced that the form of future war was predictable from studies of the weapons systems involved, for example, a study of the tactical problems which arise when an A-bomb is dropped would lead inevitably to the methods which should be used to counter its effects. The Chairman pointed out, however, that a scientific study of military history had not so far been promising, but agreed that it might be necessary to give further thought to this.

5. The meeting then went on to discuss the time scale of a future war. Dr. Paxson suggested that the use of the phrase "probability of war" was

dubious is a scientific sense. To predict the outbreak of a new war, an examination should be made of political and psychological tensions on the one hand, and to capabilities of the opponents on the other. Basing his arguments on the second of these, he said that his personal opinion was that if Russia wanted to attack the Allies they might well consider the present an opportune time. Mr. Sargeaunt agreed to some extent with Dr. Paxson but he felt that he had not taken sufficient account of the fact that the Soviet were pursuing such a winning line in the cold war that it was difficult to understand why they should want to alter their tactics. As a personal opinion, he suggested that Russia's desire to avoid a major war was so great that unless the Allies attacked, there was little danger. He suggested that there may be a little too much preoccupation with the possibility of a war in Europe and thought that, since the A-bomb may not have such an immense value in Asia, Russia might well look to an Asiatic war. The possibility that a war which began in Asia might spread to Europe was then discussed, particularly with respect to the inability of the Soviet to consider a war of attrition because of the limitations imposed by their POL supply. Dr. Gamow suggested that an important distinction could be drawn between whether a country wanted war and, if it did, what was the best date for it to begin its aggression. The Chairman then showed how the number of countries involved in war when considered as a time series showed a distribution which suggested that some random elements were involved. Because of this, he thought, one could consider the probability of war in terms of the probability that there would be war before a certain date. This, of course, would give only a broad outline for planning, but might have some value as a background.

6. In discussing the precise form of the next war, it was suggested that it was necessary to take into account, quite precisely, the date at which it was thought that the war would begin. Brig.-Gen. Marshall outlined his ideas in which the defence organised itself primarily for the protection of lines of communication and not on its territorial position. Mr. Sargeaunt and Major King pointed out the similarity of this picture with war in the Middle Ages, and suggested that some interesting analogies could be found. It was however, important to note the effect of relative changes in communications and supply.

7. As a result of the discussion, the meeting agreed that:

(a) increased attention should be paid by Operational Research Agencies to the organisation and conduct of war games

(b) that the subject "The Form and Timing of a Future War" should be a topic for discussion at the next Tripartite Conference.

Tactical Intelligence

Present: Mr. A. W. Ross, U.K. Chairman

Canada

Col. G. M. Carrie

Mr. T. K. Groves

Dr. A. C. Lauriston

Maj. J. S. Orton

U.S.A.

Dr. H. Cole

Dr. G. Gamow

Lt.-Col. H. E. Gould

Dr. J. B. Green

Dr. L. Hawkins

Brig.-Gen. S. L. A. Marshall

Dr. T. Page

Dr. E. Paxson

Dr. M. Vigneras

U.K.

Mr. R. W. Brittain

Mr. B. D. Hankin

Mr. W. H. Hill

Maj. M. P. King

Lt.-Col. V. H. B. Macklen

Mr. M. I. Rickers

Mr. H. A. Sargeaunt

Dr. I. J. Shaw

Mr. E. G. Smith

Mr. G. Wooldridge

Brief for Discussion

Tactical intelligence is more vital to the Army now than ever before; this greater need arises from the increased mobility of Armies, and from the introduction of the new weapons. For the latter, up-to-date tactical intelligence is essential for their effective use (so much so that it can even be regarded as an essential element of the weapon system), but is also necessary from a defensive aspect since the reduced density of the defending troops which will almost certainly be adopted increases the vulnerability to conventional penetrations, while there may even be gaps between forces which must be rapidly blocked in an emergency.

2. Apart from the difficulties of operating without air supremacy, photo. reconnaissance suffers from at least three defects:-

(a) it requires good visibility, in which respect it has been estimated that photo. reconnaissance from 5,000 feet should be possible in N.W. Europe for about 35% of days and 47% of nights, while we know only too well that it may occasionally be impossible for several days together;

(b) processing of the prints takes an appreciable time; and

(c) armies are becoming increasingly proficient at camouflage.

3. Some form of guided weapon may eventually provide a partial answer to the vulnerability problem, although serious difficulties must be overcome.

4. Camouflage and poor visibility may be partially met by the employment of new methods, of which high discrimination radar and thermal mapping appear the most promising, but, with these, interpretation of the resulting "picture" is likely to be difficult except in the case of a few characteristic targets. To ease this problem some form of moving target indication in association with the high resolution radar appears a requirement.

5. Other methods for detecting vehicles and troops which have been examined (e.g., the detection of carbon monoxide and ionised gases) do not appear promising.

6. It would seem that no complete solution to the problem of providing tactical intelligence immediately and whenever it is required has, as yet, been suggested.

Discussion

The Chairman opened the meeting and said that the brief only covered the collection of intelligence but he understood that there was a general desire that the scope should be widened and he suggested that the discussion should be in two parts:-

(a) Collection of Intelligence.

(b) Handling of Intelligence.

This was agreed and the Chairman then asked the US delegation to present, as a starting point, some of the data obtained by the ORO team in Korea.

The delays, as found by ORO, in obtaining Artillery information in Korea are -

Air photographs	4.6 days
Interrogation of POWs	30 hours
Air observation posts	2 hours
Shell reports	40 minutes
Sound ranging	25 minutes
FA Radar	16 minutes
Flash spotting	7 minutes

The air photography time applies to routine cover which is supplied twice per week; it is possible to obtain special cover but this takes much longer to come through. The photographs rarely show any indication of damage and POW's say that the Chinese immediately repair any superficial damage to prevent any damage assessment being made.

It was agreed that air photography was the most fruitful source of information but that it was, at present, too slow and that because of weather limitations it would not be adequate, especially in N.W. Europe.

There is also the problem, with photographs, of the enormous amount of material which has to be handled, only a small percentage of which contains useful information. The possibility of increasing the speed of this handling was discussed and the possible use of an automatic comparison method such as is used with astronomical photographs was mentioned. It was also stated that ORO are working on sampling techniques.

It was agreed that some method is required for handling photographs or alternatively some method of collecting intelligence is required which will be more selective than visual photographs.

This led to a discussion of alternative methods of collecting information. The possible advantages in selectivity of thermal mapping were pointed out but it was thought that there may be some difficulty in interpreting the "picture". It was also stated that although thermal mapping would be affected by fog, rain, cloud, etc., it would not be seriously affected by mist, etc. Millimeter radar was also discussed and its advantages from both these aspects was mentioned. It was agreed that both of these equipments deserved to be tested in the tactical intelligence role and that the development of airborne equipments should be encouraged.

The US delegates also mentioned a device with a small radio transmitter which sends back all sounds which are picked up and which can be fired from a gun. It was stated that the cost is not much more than two artillery shells of the same calibre and that the battery life is 2 - 4 hours.

The advantages of detecting movement were discussed and it was agreed that MTI was potentially a very useful technique. The meeting then went on to discuss the adequacy of the present means of transmitting information and it was stated that in the US Army 93 (Operations) messages are passed ten times faster than G2 (Intelligence) messages. Since the staff and equipment are similar there is clearly something wrong with the G2 procedure. For the British Army it was said that during major exercises in Northern Army Group it takes on the average two to three hours for a piece of intelligence information to reach the Chief of Staff NAG and that a time of 40 hours has been recorded. These times are clearly unsatisfactory and there is no point in speeding the collection of information if its transmission is going to be so slow.

The US delegates expressed great interests in the British 'Phantom' organisation (now called 'Signals Reporting Regiment') and asked whether it would be possible to include a Regiment in one of the major Northern Army Group exercises. It was agreed that this was desirable and that the U.K. should attempt to make the necessary arrangements.

The discussion then turned to the staff required for intelligence work and their training. The difficulty, in peace-time, of training intelligence officers and of attracting the right type of officers to these posts in peace-time were discussed as was the allocation of intelligence officers to British Division and lower formations. The latter was generally considered, to be rather meagre. The opinion was expressed that at Division and possibly at lower levels there is a requirement for officers who have been trained to recognise important items of information with facilities for passing these items on directly.

Finally machine methods for the storing and analysis of intelligence data were discussed and it was agreed that Operational Research could make a valuable contribution in the application of this technique.

Conclusions

1. The present procedure for handling tactical intelligence is too slow for this new weapon. Information should be screened at the lowest practicable level and passed direct to the action level.

2. An all-weather method of collecting tactical intelligence, which is selective to important targets, is required to supplement photographic reconnaissance and to reduce the demands for bulk cover. In addition improved means for the rapid identification of important targets in reconnaissance photographs are required.

3. A study of the selection and training of Intelligence Officers is desirable.

4. There are many unexplored possibilities for gaining more intelligence of tactical military value from information presently available (and largely unused) in the army intelligence system. Operational Research can make a valuable contribution by codifying procedures for the exploitation of such unused information, involving statistical methods, suitable information storage methods, etc.

Recommendation

The U.K. should investigate the possibility of incorporating a Phantom Signals force in a major exercise, which United States and Canadian observers might be invited.

What can Operational Research do in the Field of Training

Present: Dr. T. W. Cook, Canada, Chairman

Canada

Mr. J. E. D. McCord

Maj. F. G. B. Maskell

Dr. N. W. Morton

Maj. J. S. Orton

U.S.A.

Dr. S. W. Davis

Miss G. Donovan

Dr. J. B. Green

Dr. D. Meals

Dr. T. Page

Col. D. C. Tredinnick

Dr. M. Vigneras

U.K.

Lt.-Col. D. G. Davies-Scourfield

Mr. G. N. Gadsby

Mr. L. J. Holman

Mr. H. Murray

Dr. J. C. Penton

Brief for Discussion

1. In a previous session the aspects to be evaluated have been divided into weapons, tactics, and men. Attempts to evaluate the first two are familiar to Operational Researchers; we will assume that it is also desirable to evaluate the men. This last concerns the broad fields of selection and training. In the present outline we will take selection for granted and discuss only training.

2. Assuming the desirability of evaluating training, the problems involved may be divided into those that are common to all evaluation, and those that are specific to training. It may be stated that the latter bears so differently on different aspects of training that the major problem is not whether operational research on training should be done, but how to select operational research training problems, methods, and techniques that will give maximum return for effort expended. There are few research areas where it is easier to use time and effort uneconomically.

3. Fisher, in a paper on Operational Research in Training prepared for the Commonwealth Conference on Defence Science, has divided the topic into five areas. (a) Job Analysis - what is the job? (b) Selection - who is to be trained? (c) Instructors - who is to do the training? (d) Methods - how is the training to be carried out? (e) Measurement - how is the state of training to be determined? For present purposes we may omit (b) selection, and combine (c) and (d). This leaves also the problems of job analysis, training and measurement. It will also be convenient to somewhat arbitrarily divide what men do in the army into three stages, basic and corps school training, unit functioning in camps (exercise, schemes, trials), and actual fighting. One of the added difficulties in evaluation of training as compared with weapons and tactics is that a given soldier is not the same man at each of these three stages. Once a weapon is made it can only be worn out, but with a man the training process is continuous.

4. The importance of the common sense aspects of job analysis for all evaluation of weapons, tactics, and training, is well recognized. Particularly in war, when the materials and methods of fighting are in constant change, it is important to feed back information from the front line to the training centres. Usually this is done through some sort of rotation scheme, so that a steady flow of men with battle experience return and assist with training. Operational research observers have for a long time been accepted at the front to assist in evaluation of weapons and tactics. To what extent can they also evaluate training? Such observers would have two functions: (a) Study of battle and preparation for battle, and discussions with front-line personnel. This would assist in ensuring that what is taught, and the length of time devoted to each topic is kept in line with battle conditions. (b) Observation of the state of training of reinforcements. This could only be roughly estimated, but major gaps could be noted with advantage.

If Operational Research observers on the front line are desirable, what sort of personnel are needed? How should these carry on their observations. (What, for example, is the value of the technique developed by General Marshall of the U.S. Army)? How should the information be fed back to the training centres? How can its use be insured when it is fed back? Should OR effort in the training field be concentrated wholly on this type of observation and resulting ad hoc advice with no attempt at quantitative measurement or experimental design? Obviously the results of this type of study can be used to evaluate both school and regimental training against battle conditions, and also the results of the first against the second. Some Canadian work in this latter area is under way at Fort Churchill and Edmonton.

5. The survey type of assessment of the results of training can be supplemented by measurement: in schools, in units or in battle operations. Here the aim is merely to quantify the results of observations against some scale. To some extent measures of efficiency such as number of hits on a given target, at present used to assess the performance of weapons and tactics, can also function as criterion for assessment of training. The performance of a man is so varied and complex, however, that additional

assessment measures are needed. Even in the training centres, for example, present assessment of knowledge and skill are highly unsatisfactory. Assuming that short answer tests are our most manageable tests of knowledge, can service personnel be adequately trained in the construction of these? Can satisfactory tests of skills be developed? More difficult still, can sufficient time be found to test all men thoroughly? Our experience in the Canadian Army would lead us to believe that the British TOETs are satisfactory tests, but that there is never time to use them properly. Further, can anything be found out about the state of training if testing is left in the hands of instructors: must all examining be done by trade boards or travelling teams?

Finally, should measurement be confined to those factors (such as specific skills in weapon handling or carrying out routine order) that are much the same in training and on-the-job performance, and are therefore easy to measure and assess? Or are other aspects of the performance so important that an attempt must be made to measure them in spite of obvious difficulties?

6. The possibility of controlled experiments follows from the construction of measuring devices. The typical field experiment has been a comparison of two methods, trainers, or techniques, by the use of an experimental group (taught the new method) and a control group (taught the old or no method). The groups are, of course, equated, training is otherwise equalized, and results measured. The use of the experimental method in schools, for evaluating those feature of training that are unchanged on the job, is not difficult if measuring techniques are devised and time found to apply them. On the other hand, experimental testing of such a device as a synthetic trainer against battle performance is impossible in peace, and probably absurd in war. Checking the results of basic and corps school training by performance in exercises and schemes is possible, but extensive and expensive, and useless unless carefully controlled. That means that for each experiment, a large scheme must be especially laid on, the design must be vetted by experts, and nothing must be allowed to change while the experiment is in progress. Failure to do this has led to some spectacular fiascos.

Accordingly field experiments should only be undertaken if the point at issue is of sufficient importance to justify careful planning and the trouble and expense to the army that is involved in rigidly adhering to the necessary conditions.

Discussion

1. The Chairman opened the discussion by stating that he would assume an affirmative answer to the question: has operational research any value in the field of training? Whenever a team has investigated training in the past, he said, the results had been of assistance in solving the problem. He would therefore take it for granted that operational research in training is of value; and this proposition was later adopted as the first part of Conclusion (a).

2. As a general basis for the discussion, the Chairman placed on the blackboard the following table, so that delegates could see how and where points raised later fitted into the whole scheme.

	1	2	3
What is evaluated	Weapons	Tactics	Men
At what stage	Schools	Exercises	Combat operations
What methods	Survey	Measurement	Equipment
What technical problems	Job Analysis	Training: Syllabi Methods Devices Instructors	Measuring devices

3. The Chairman then proceeded to inform the group of some of the problems of exercises in the North, in which Canada is particularly interested. Troops unfamiliar with the North, he said, began by being afraid of the cold, and afraid of being lost. Ordinary domestic economy took up a large proportion of a man's time - in fact, experimenters had each to have a soldier to look after them, to do their chores, or they themselves would have got no work done. They found that a compass and the counting of paces were adequate for their 'navigation' in ordinary circumstances, but the problem remained whether every soldier could be trained to navigate successfully in this way.

4. Dr. Meals then spoke about the decision to work on the problem of setting up criteria for infantrymen. He quoted the Superintendent, A.O.R.G., as saying that the basis of our problem is "proportion of effort". Having decided which capabilities in the soldier were important, how did we settle priorities in obtaining them?

5. He explained that they had not done much experimental work, (using the word 'experimental' to mean investigations in which the experimenters manipulated the variables) except in so far as they had selected troops for investigation and matched them with control groups, etc. From 'critical incidents' (observations of men's actual behaviour in combat by their leaders), they had developed a check list which had a reliability of more than 0.9. This formed a basis for comparison with new combat situations in the future.

6. Dr. Meals went on to explain further that the basic problem of assessing the training of the infantryman is the criterion. Four measures had been used:

(a) A rating technique. Squad leaders rated their men according to their effectiveness in combat.

(b) 'Buddy-rating', in rank order, of every man by every man.

(c) A check list questionnaire, using 'forced choice' technique.

(d) Reporting of critical incidents.

These measures, he said, were made as soon as possible after the men had been in combat.

7. Dr. Green suggested that the reliability figure 0.9 quoted was really a figure for internal consistency and not for reliability. In reply to this Dr. Meals said that we could find which behaviour acts correlated most closely with the criterion. The difficulty arose in the question of relative weighting.

8. Col. Tredinnick felt that in investigations of this nature, there might be a danger of obtaining a sample which was not truly representative; for example, a higher percentage of the best men might be killed in action. He felt, too, that the study was aiming to test combat effectiveness, but without having first defined it. Dr. Meals replied that the investigation was directed towards trying to obtain a definition of combat effectiveness.

9. Dr. Page wondered whether this investigation might not result in homogenizing the Army so far that everyone would have the same training. The Chairman asked whether results of the study would apply to infantrymen only, or could they apply to artillerymen as well.

10. Dr. Meals replied that when thoughts and ideas had been clarified, we should be in a position to say what qualities are necessary in a good infantryman. Whether those qualities would apply to artillerymen and engineers as well was a question which could only be answered by application of the techniques to these subjects. He thought it possible that there would, in fact, be a large overlap in the qualities required, and to that extent only would feel justified in recommending a homogeneous training.

11. It was suggested by Mr. Gadsby that it would perhaps have been better to have begun the study with one of the technical services rather than with infantry. The technical personnel formed a larger portion of the Army and their training was far more expensive. It was stressed by Dr. Meals, however, in reply, that the general principles and methods should be applicable to all arms. Development of method was the aim.

12. The meeting then discussed the question of the application of these methods in the field. Some delegates considered that since the methods had been developed, their application and the analysis of results should be done by military personnel, whereas others felt that because of the pitfalls and snags inherent in this type of work, operational research should be used. After an exchange of views on the subject, the sentence forming the last part of conclusion (a) was agreed.

13. The Chairman then called on Dr. Penton to outline the work on training done by AORG.

14. Dr. Penton explained that AORG's work on training arose from a request from very high level to look into the question of the shortage of tradesmen in the Army. This shortage could spring from two possible sources:

(a) from a real shortage of trainable men, or

(b) from the fact that men were trained to standards far higher than was really necessary.

The trades investigated were mainly those which were much the same in peace as in war. Observation was mostly used, but for RAC Drivers and RAC Signallers, pencil and paper tests of their knowledge were applied, and the results compared with the training syllabi. It was generally found that the standard of the syllabi was too high and needed revision. This finding was usually not very well received. On eight occasions it was pointed out that the choice was between having insufficient tradesmen of too high a standard and having sufficient men of a lower standard.

15. AORG was also trying to investigate the actual use of tradesmen in the field. It appeared that in some cases it might be possible to reduce the

number of fully-trained tradesmen by 50%, by using men with lower qualification and a proportion of G.D. men.

16. There was also plenty of room for improvement in training methods, Dr. Penton continued. AORG had developed a PPI simulator for the selection and testing of Operators Fire Control.

17. Dr. Penton went on to say that AORG had tried to obtain a shift of emphasis from the theoretical side to the practical. There was also the question of 'further training'. Which could be done here. Changes in training organization had been recommended. There was also the question of the interruption of a recruit's training by general duties, e.g., by general duty, fatigues, drill and parades. It was the opinion of AORG that in some cases, e.g., training of drivers, such interruption was not harmful, whereas in other cases, e.g., training of Morse operators, such interruption caused serious inefficiency. In such cases, the trade should be taught first and the soldiering later.

18. AORG had also carried out some trials with the EM2 rifle. Six recruits had been trained with the present No. 4 rifle and six with the semi-automatic EM2. The results had shown that (except in one minor point) the shooting with the EM2 was far better in every way. The unit had compressed their rifle training programme into 18 days; and the Small Arms School at Hythe had now taken up the whole question of the rifle training syllabus. Because of the shortage of research personnel, this was a good thing. If the enthusiasm of the Army schools and instructors could be fired, it would then be necessary for operational research personnel only to keep an eye on their methods and to see that their results were scientifically validated. The more work done by the unit itself the better, as they were then more likely to see the necessity for and to accept the recommendation.

19. Another investigation in which AORG was now engaged was to see whether it was better to keep men in the same squadron throughout their entire training period, or to change them fron one squadron to another as training progressed.

20. AORG was also involved in a study of the teaching of Morse to signallers. It was discovered at the outset that the Navy in the same time, trained men to higher standards, and that in Canada men were brought up to the same standard as our Army signallers in a shorter time. The investigation has led to radical changes in the training organization.

21. Mr. Murray said that the teaching of Morse was a subject which kept cropping up. At first sight it appeared to be a straightforward investigation; but the instructors had had many more problems to discuss, in addition to that of teaching Morse. He found that he was acting as a catalyst in the unit and that all problems had been brought along to him. In most cases, the solution had been an obvious one. The people concerned knew what should be done, but there was so much inertia in the system that the drawbacks were accepted as inevitable. They had not adapted the training to suit changing conditions.

22. The Chairman asked whether the resources of research personnel were sufficient to enable people to be placed in every unit for this purpose. He pointed out that the Army was very fluid, with instructors changing continually. New instructors would not know why things were being done the way they were, and would alter them. How was it possible to implement this.

23. Dr. Penton replied that this could be implemented only by introducing into the training machine a section whose job it was to know why alterations were introduced. The more technical the training became, the more the necessity for a greater degree of permanence amongst instructors. The problem was to find scientific evidence of its necessity.

24. Major Maskell suggested that in order to get good instructors it was necessary to change them frequently, so that they would get all-round experience and knowledge. Dr. Penton pointed out that in places in the Army an establishment of civilian instructors was accepted. He thought that flow might

be necessary for Army officers, but it might result in defects in the training programme.

25. The Chairman asked whether it was generally agreed that a study should be made of the efficiency of the machinery of change-around of instructors, so as to discover the best system. This was agreed and included in conclusion (b).

26. Dr. Meals said that it was his opinion that an enquiry was needed into the costing of training, which should be included when assessing the relative effectiveness and cost of weapon systems. The cost of training men to operate and maintain different systems might differ considerably.

27. Lt.-Col. Davies-Scourfield, however, suggested that while costs might be important in peace-time, in war-time the most efficient system must be used, regardless of cost. To this Dr. Morton replied that cost here represented man-hours, so the last remark was not necessarily true. A decision would have to be made as to what proportion of the national war-effort should be expended in each direction.

28. The Chairman said that the economics of study itself was difficult to assess and wondered whether one sizeable study could be carried out which could be generally used.

29. Dr. Meals said that such studies were being carried out, and training costs should be included. So far the matter had been raised only abstractly. Dr. Penton said that AORG had been involved in such problems, as for instance in the supply of electronic armament artificers.

30. Conclusion (c) was agreed as a result of this part of the discussion.

31. The Chairman then returned to the question of the standard of mathematical and physical theory required in the training of tradesmen. He said that theory could be made interesting, but wondered whether it was of much use to the tradesmen, and wondered whether all the necessary theory could not be taught by the use of mechanical working models.

32. On this point, Dr. Davis said that in the past it had proved difficult to get enough men through the pencil and paper tests for airplane mechanics. The selection methods had then been changed, a more practical course of teaching had been adopted, and the overall result was that better mechanics had been obtained.

33. After further brief discussion on this point, conclusion (d) was agreed.

34. In all, in the course of the discussion, the following four conclusions were generally agreed:

(a) It is feasible and useful to undertake, in the combat zone, studies of human performance which have implications for improvement of training. For this purpose, further developments of methods is desirable. These should include methods that can be used by military personnel where operational research workers are not available.

(b) A study of methods should be made by which operational research workers can facilitate modifications within training units largely by the efforts of the units themselves, and of means of ensuring permanence of improvements introduced.

(c) It is desirable to conduct cost analysis of training in order that this information may be included in the overall comparative evaluation of weapons, equipment and training.

(d) Emphasis should be placed on investigation of problems (such as techniques of teaching abstract principles by visual aids), the answers to which have wide applicability in training situations.

The Army's Requirement for Air Transport

Present: Dr. J. K. Tyson U.S.A., Chairman

Canada

Mr. G. D. Kaye

U.S.A.

Mr. A. H. Moore

U.K.

Mr. R. W. Brittain

Mr. S. W. Coppock

Mr. A. H. R. Lockwood

Mr. S. H. C. Mound

Major D. Norman

Mr. G. Wooldridge

Brief for Discussion

1. The use of airborne troops and the use of air supply are relatively new additions to the art of land combat, and there are still major differences of opinion over the optimum extent of such use. In this discussion we shall explore how operations research can contribute to the solutions of the problems raised.

2. It is desirable, at the outset, to distinguish between the various kinds of operations involving transport aircraft. In the US Army these are broadly classified as Airborne and Air Transport operations. Airborne refers to the deployment of military units, together with their equipment and supplies, to accomplish a particular mission of either tactical or strategic nature; Air Transport refers to the administrative movement of personnel and supplies in indirect support of military operations. These categories overlap to some extent, and they are properly considered jointly, not separately, in the formulation of requirements, since only a limited specialization of aircraft and employment appears to be feasible.

3. The 'requirements' for air transport are both qualitative and quantitative, i.e., decisions involve both the design characteristics of the aircraft and the number to be procured. These two aspects are interacting, of course. Nevertheless, the following comments are from the point of view of the strategic planner, who takes technical characteristics as a datum and goes on to decide how many aircraft are required.

4. Of the two broad categories, airborne operations are the most difficult to evaluate. The factors involved, speed, mobility, cost and sacrifice of supporting combat forces - are well known quantitively and can separately be subject to numerical evaluation. What is lacking is a common measure of value to show in a given situation, the desirable allocation of a nation's resources between airborne and conventional military capability. This difficulty is not specific to the subject of airborne operations; rather it is a reflection of the limited progress of the science of combat.

5. The evaluation of air transport allows a narrower viewpoint. In this aspect the air line of communication supplements or replaces the surface logistic pipeline with only an indirect relationship to combat operations. A comparison of the two seems more readily achievable at least in principle. A difficulty arises from the fact that the criteria for an optimum pipeline are not thoroughly understood. Due to the lack of a common value measure one does not know, for example, how to decide what military effort should be expended to provide the flexibility needed to meet highly variable demands for supplies. A partially satisfactory approach is to take as specified each of the various attributes of effectiveness and compare the required air and surface transportation alternatives on the basis of their costs. Such a procedure will be as valid as the definition of the constraints, and at best can yield only the conditions under which surface transport should be exchanged for air transport. Roughly one may say that air transport is used:

(a) when geographic limitations permit no other alternative

(b) when the surface L of C cannot fulfil the supply requirements with the desired promptness

(c) when air transport is more economical than surface transport, and

(d) when the special characteristics of the cargo require a short transit time.

6. For the reasons outlined before only (c) can be readily subjected to analysis; the others strongly involve poorly understood values relating to combat effectiveness. Although (c) has probably been one of the less important reasons for employing air transport in the past, it would seem to be largely on this basis that one could justify the planning of a large increase of air transport capability.

7. A closer look at the economies of air versus surface transport shows a variety of possible savings. The following is suggested as a tabulation of the costs pertinent to the comparison.

(a) Transportation Costs

  (i) Operations

  (ii) Facilities

  (iii) Handling

  (iv) Cargo loss and damage

  (v) Attrition

(b) Transit-time Costs

  (i) Earning power of material in pipelines

  (ii) Perishability and obsolescence

(c) Prediction Costs

  (i) Overseas or advanced base storage

  (ii) Excess supply.

In a given situation the relative magnitudes of these costs, and the comparison between surface and air transport, is dependent on the nature of the cargo, the principal cargo characteristic being the value per pound. Within the limitations already set forth the cost evaluation will provide at least a partial basis for estimating requirements for air transport.

Discussion

1. The Chairman opened the discussion by stating ORO interests in this subject and explained the American system of air transportation. He defined the USA airborne and air transport operations. Although these definitions are not exactly the same as those of the British, they do overlap to some extent, and the essential nature of the problem is not altered.

2. The UK delegation thought that the aircraft used in operations should be rear-loading and capable to being used both in the airborne and in the air transport roles. The use of transport aircraft could do much to reduce the number of garrison troops overseas. Supplies and equipment could be stock-piled at vital points and the troops could be flown out to join up with them when necessary. The USA delegation concurred, and the Canadian delegation intimated that Canada already had something of the sort in her "mobile striking force".

3. The UK delegation suggested that commercial firms should be encouraged to develop and operate transport aircraft of military specifications. The USA delegation, however, insisted that, since the civilian economy was not at present in a position to undertake the task, it must remain a military one.

4. The meeting agreed that for the efficient use of air transport, it was desirable that the aircraft should spend the maximum possible time in the air. The idea of a detachable 'pod' was interesting in this respect, but the USA delegation considered that a major drawback of the pod was that it decreased the possible payload of the aircraft.

5. The use of helicopters was discussed at some length. As far as their use by the Air Forces was concerned, the UK delegates thought that the RAF was not particularly interested, whereas the US members said that their Air Force found a useful role for helicopters in pilot pick-up etc. In the American forces, all three Services operated helicopters.

6. Some details of the future organization and equipment of helicopters were given by the UK delegation, and useful roles for helicopters were enumerated. It was pointed out that supply by helicopters would not be affected by the problem of refugees on the roads. The British view on the maintenance of helicopters was more optimistic than that of the USA delegation, who said that the ratio of maintenance time to flying time was of the order of 8 : 1 and that the maintenance and support of aircraft was a major worry in Korea.

7. The USA delegates asked if the supply system should be altered to incorporate air transport, or if it should be regarded as supplementary to the present system. Could stock levels and reserves be reduced?

8. It was suggested that a study should be made of the best use of the available air transport. Could priorities be laid down? The important factors are time, vulnerability and the earning-power of goods in the pipeline. The USA delegation pointed out that the vulnerability of the carrier and the characteristics of the cargo were unknown quantities. For example, items which are to be consumed quickly are more valuable than those which are to be stored after airlift. The Canadian delegation called for a historical case study, to be combined with war games.

9. The meeting agreed unanimously that the problem of air transport should be kept under review.

Manpower Problems Created by New Weapons Systems

PRESENT: Mr. S. W. Coppock, U.K. Chairman

Canada

Colonel C. R. Boehm

Colonel G. M. Carrie

Mr. I. H. Cole

Dr. A. C. Lauriston

Mr. J. E. D. McCord

Dr. N. W. Morton

Dr. A. J. Skey

U.S.A.

Miss G. Donovan

Mr. J. H. Henry

Dr. D. Meals

Mr. A. H. Moore

Colonel E. M. Parker

Colonel D. C. Tredennick

U.K.

Mr. C. L. Barham

Mr. D. F. Bayly Pike

Mr. E. Benn

Mr. L. J. Holman

Mr. A. Lockwood

Mr. S. H. C. Mound

Dr. J. C. Penton

Mr. R. W. Shepherd

Mr. G. S. Stewart

Brief for Discussion

1. New weapons systems are generally introduced for one or both of two reasons, either to perform the task of the present system more efficiently or more rapidly. For example, a new gun may fire a more effective shell or it may have a higher rate of fire. A new bridge may be designed to carry a heavier load or to carry the same load but with greater speed of construction.

2. In such cases the general effect is to maintain or slightly decrease the number of men required to operate the system and in those few cases where a reduction is effected, the reduction is not very great. At the same time, all such improved equipments, because of their greater effectiveness, tend to be more complex in manufacture and maintenance. There is therefore a call for more skilled manpower so that the net effect of the introduction of a new weapons system is usually to maintain the overall manpower requirement but to raise the proportion of skilled manpower within that requirement. The problem thus resolves itself into one concerning the allocation of skilled manpower.

3. In olden times Armies had to make do with brute force and ——— ignorance! They did by weight of numbers things which in industry were done by machinery; but those days are a thing of the past and the Army can no longer accept the dregs of the labour market but must have its fair share of the skilled manpower pool. This pool is however of very limited dimensions, and, when it is pumped dry, there are no new sources to tap. We must therefore be very careful in our use of the limited supply of skilled manpower available to the Army.

4. Of recent years with the introduction of radar, complicated signals equipment, tanks with stabilizers and range finders and now guided missiles, the demands for skilled labour in the Army have increased tremendously.

5. One attempt to solve the problem has been the simplification of the end product (for example, push-button radio) but that usually results in an increased demand on the repair and maintenance staff.

6. The training of conscripts in a skilled trade, followed by refresher courses during their period in the Reserve, is another attempt to provide the requisite body of skill. In theory it is perfect but somehow the results in practice have not been very impressive.

7. To increase the Army's allotment of the nation's skilled manpower would merely mean that the industries making the Army's weapons and equipment would be correspondingly fleeced and that would reduce the rate and/or quality of the supply of arms.

8. To train all the Regular soldiers - even if they had the necessary ability - to the standard of skilled craftsmen would not solve the problem because the tasks of the Regular Army upon mobilization are:-

(a) to hold the line and

(b) to train the incoming reserves and conscripts.

9. As an example, let us look at the surface-to-surface guided missile. Skill is required in its manufacture; skill is required to assemble and fuel it on site; skill is required in the fire control. The testing of the weapon at the launcher can be reduced to a series of "go, no-go" tests which any man can perform, but the test equipment for this is massive, expensive, and complicated. This test equipment must itself be checked and maintained, for without it the whole guided missile battery becomes impotent.

10. What then should the Army do to combat this scarcity of skilled labour? In what ways can operational research help to solve this very important problem?

Discussion

1. The meeting first discussed the general question: Does a manpower problem exist and is one likely to exist in the future? It was agreed that there was already a problem especially in those cases where, following new technical discoveries, new specialized skills were required. While new weapons might achieve, with fewer men in the field, effects comparable to the weapons they replaced, the overall demand for effectiveness was nevertheless always increasing and the proportion of specialists required was higher than before.

2. The meeting went on to discuss the nature of the demands on skilled manpower and the resources available, either directly or with conversion training, and methods by which these demands and resources could be measured.

3. It was agreed that the need for skilled manpower, whether in fighting, maintenance or production was closely related to the complexity of equipment designed to meet exacting military specifications. It was felt that a broad form of cost-effectiveness balance, taking into account the expenditure of skilled manpower, would show that some specifications, despite high performance figures were, in fact, uneconomic. In spite of the fact that there was, as yet, no satisfactory method of including skilled man-hours in a cost assessment, it was felt that efforts should be made to scrutinize military performance from the point of view of overall economy. It had been shown that much could be done by human-engineering studies of specific systems to reduce the needs for skill in operation, maintenance and handling, and it was felt that such a study should be made at the earliest possible stages of equipment design in order to develop its greatest possible effectiveness. In addition it was considered the extra effort necessary in design to effect a substantial improvement in reliability was usually not great, especially when the consequent reduction in maintenance load was taken into account.

4. The meeting considered that the most obviously serious shortages occurred in the field of electronic equipment and that it was important that other fields should also be studied. The technique of job analysis should enable the necessary skills in any particular case to be evaluated, and it should then be possible to relate the skill requirements to the results of appropriate tests. It was clear that the tools here are at present crude, but it was thought that they are capable of sufficient refinement.

5. While it might be possible, it was felt, to state the skill and manpower requirements for, say, a GW troop, the overall problem could not be studied without a knowledge of the numbers of such troops to be raised. It was considered that Operational Research was here in some difficulty since it had insufficient foothold in the Planning field.

6. While there are few military tasks which have exact counterparts in civilian life, it was agreed that the general civilian level of technical knowledge and skill was increasing markedly, and that the introduction into civilian use, for example, of television and telearchics was making a great proportion of the population familiar with some, at least, of the concepts and techniques of radar and guided weapons. In peace-time there was, correspondingly, competition with the Services for specialist personnel, though some attempts were being made to direct the interests of potential specialists into military channels. The difficulty of making a valid assessment of differences in technical manpower, either over the years or between different countries was stressed.

7. A large-scale survey of the aptitudes and capacities of American high-school students was mentioned as a useful starting-point. Such a survey should indicate the trainability of personnel in differing fields, in addition to their probable skills in selected fields. It was felt that such a technique would be satisfactory, provided that measures and terms used could be related to those of the job analysis, and it was suggested that an attempt should be made to apply such methods to a specific equipment, for example, a guided weapon.

8. In the matter of training, the view was generally expressed that often

more is demanded of military trainees than is necessary in their duties.

9. It was agreed that it would never be possible to satisfy all the requirements and some kind of optimization must be arrived at lest it was eventually found that there were too many personnel engaged in technical work and too few fighting the battle. An overall study of this kind could be carried out only in relatively crude manner, but was considered an essential preliminary to making specific studies, in order that the most critical areas could be identified.

10. Any overall model would have to be capable of including the effects of time on resources. The shortages created by a new weapons system would tend to be most serious initially while leeway was being made up, and the trainability factor would, therefore, have to be included.

11. The meeting agreed the following conclusions:-

(a) It was advisable for each of the three countries to formulate a dynamic model to show the trends of military demands on its national human resources and potentialities. Comparison between the models should be maintained.

(b) It would be helpful if estimates of the manpower and skills required to fight, maintain and produce new military equipment, were made in some important cases at least, and preferably as a routine. Skills should be evaluated in terms which can be used in personnel selection and manpower planning.

(c) Surveys of total military manpower and skill requirements based on the above should be conducted. These should be brought to the attention of the agencies responsible in each country for education and training to help determine national training policy, and the authorities responsible for manpower allocation in times of emergency, so as to relate military to overall national needs.

(d) Any means of reaching a balance between the supply and demands of skilled manpower should in any case be encouraged. In particular, designers should examine how their equipment can be simplified for operation, maintenance and production, and, with the military authorities, should balance performance against demands on skilled manpower.

Fatigue and Stress

Present: Dr. S. W. Davis, U.S.A. Chairman

Canada

Dr. T. W. Cook

Maj. F. G. B. Maskell

Dr. N. W. Morton

Dr. A. J. Skey

U.S.A.

Miss G. Donovan

Dr. D. W. Meals

Lt.-Col. D. E. Munson

Col. E. M. Parker

U.K.

Lt.-Col. D. G. Davies-Scourfield

Mr. G. N. Gadsby

Mr. L. J. Holman

Mr. S. H. C. Mound

Dr. J. C. Penton

Dr. J. W. T. Redfearn

Brief for Discussion

1. The primary operations research consideration in the area of fatigue and stress is the problem of providing infantry commanders with more accurate information on which they can base such decision as: how far a unit can be expected to go; how long men should remain in combat; which, of several units, is in best condition to participate in combat; and whether at a particular juncture, a unit should rest or press the attack?

2. Since there is sufficient general understanding of the problem area, practical methodology and operational problems should be discussed rather than spending valuable time in specifically defining fatigue and stress.

3. Stress will be considered as a factor in combat effectiveness and consideration will be given to the three major phases of the problem, namely:

(a) The stress that combat imposes on the soldier; for example, fear of being killed or wounded, fear of not performing satisfactorily, and the actual physical exertion required.

(b) The physiological and psychological changes which occur with the stress; for example, changes in constituents of blood and urine due to adrenal activity, changes in finger tremor, perceptual motor skills, and visual and auditory sensitivity.

(c) The factors which can modify the effects of stress; for example, quality of leadership and training, extent of the soldier's combat experience, his attitudes, and the nature of the military task. These modifiers of stress are the factors which the military can control to some degree.

4. Within the framework outlined above, the following specific research problems appear to be most important, if the primary military problem is to be answered:

(a) What are the time relationships in the development of, the duration of, and the recovery from combat stress?

(b) What are the intra-relationships of the various physiological changes (e.g., esinophils, lymphocytes, 17 ketosteroids and circulatory changes) and the various psychological changes, (e.g., lowered visual and auditory sensitivity thresholds) occurring during and/or after stress? What inter-relationships can be shown between the physiological and psychological measures? Finally, what appear to be the most desirable areas for securing simpler physiological and psychological indices for stress which are amenable to use in combat?

(c) What is the relationship of the degree of change in the physiological and psychological measures to actual combat effectiveness? And what are suggested means for determining this?

(d) What information already available to commanders correlates with those more complex physiological and/or psychological measures found to be sensitive stress indicators?

Discussion

1. In his opening remarks the Chairman said that he would prefer that the discussion should deal with research methods rather than with generalities. Research in this field at ORO was directed mainly towards the solution of problems such as:

how long can a man fight for?

how often should units be replaced or relieved, and when?

when does the state of the man in the unit render it unwise to press forward an attack?

Research on the selection of soldiers who are not prone to fatigue was the responsibility of the Adjutant-General; the design of equipment, clothing and kit which would reduce fatigue to a minimum was done by the Quartermaster Department.

2. The Chairman then outlined some of the research methods available. He presented physiological data from combat troops in Korea, in which the white blood cell count indicated profound stress after 18 hours of severe fighting, and from which the unit as a whole recovered between five and 22 days later. The unit sustained 70% casualties, and yet some individuals in it, when judged by the same criterion, suffered no stress at all.

3. Using another indicator of adrenal cortical activity, he had found that one company, after a short, sharp fight, had a slightly lower ketosteroid output but an abnormally large response to the injection of ACTH. A similar state of affairs was noticed in a group of psychiatric casualties. But on the other hand, a company, after five days of steady fighting, showed a low ketosteroid output which was not augmented by the injection of ACTH.

4. What these physiological findings meant in military terms required much clarification. The men in the unit which had suffered 70% casualties were obviously jaded, and had in fact been pulled out of the battle, but on whose decision he had not been able to discover. Someone, however, had decided that the men were unfit for further action, so that, in a sense, there was agreement between the physiological data and the military decision. But taking each man individually, there was no correlation between his adrenal cortical activity and his commanding officer's assessment of his fighting efficiency.

5. Succeeding speakers agreed that such stress data offered good hopes of a measure of combat effectiveness, and stressed that a great deal of work was necessary in correlating military data with the results of such tests. Dr. Meals said that in work directed along such lines, an anxiety scale developed by his group differentiated effective from ineffective soldiers as rated by their commanders.

6. The question of the time-course of an individual's stress in battle was taken up by Dr. Cook, whose impression it was that stress was extremely severe in the first day or two, decreasing fairly sharply and then increasing again slowly over succeeding days. Dr. Penton said that although figures were not available, it seemed to him that the incidence of psychiatric breakdown in battle lent support to this hypothesis. In the first day or two there was a crop of breakdowns in the green troops, then a lull, followed by more and more breakdowns in seasoned men. Indeed, it was now agreed among Army psychiatrists that a man could tolerate only a limited time in battle without breakdown. It was, however, pointed out that as the more susceptible individuals break down sooner, a study of the psychiatric casualty rate with reference to time spent in battle would be somewhat difficult to evaluate.

7. The probable point of view of the infantry commander was expressed by Lt.-Col. Davies-Scourfield, who wondered whether there was such a very important need for finding out how long to keep troops in battle. The good commander knew when his troops had had enough, and in any case the time for pulling out or pressing on was usually determined by other factors. If

sentries were not alert, if usually cheerful men no longer cracked jokes, and if the troops became much more jittery than usual under shell-fire, then the commander knew that they were under severe stress.

8. Other speakers doubted whether any two commanders would always agree, but felt that commanders could contribute a great deal from their experiences if suitable questionnaires were devised with a view to finding out what were the signs and symptoms of fatigue which each commander looked for in his troops. It would also be informative to ascertain the degree of agreement among commanders on the subject.

9. While doubting the value to the commander in battle of more detailed scientific knowledge of stress, Lt.-Col. Davies-Scourfield said that such knowledge would be invaluable for planning purposes. If the severity of battle could be forecast, it might prove possible to give a figure for the length of time a unit should be kept in battle, the proportion of the time which should be spent in resting and so on, in order to keep stress within recoverable limits.

10. The Chairman said that in view of the unknown factors in every battle situation, he was somewhat pessimistic about ever being able to give such figures.

11. Dr. Morton thought that one of the main objects to quantitative work was the fact that it was not yet known how far one type of stressful situation can be substituted for another in research. Does prolonged exposure to cold cause the same type of stress as do other adverse circumstances? Dr. Redfearn said that the clinical psychiatric pictures in many types of fatigue were remarkably similar. There was apathy, loss of affect, loss of initiative and vigilance, and a widening gap between what a man could do and what he thought worth doing. It could all probably be summed up as a tendency towards Pavlovian inhibition in the cerebral cortex, and suitable tests involving the formation of conditioned reflexes and their extinction or inhibition in some other way could be developed. Meanwhile the fatigue tests devised by Dr. Mackworth and Dr. Fraser in Professor Bartlett's laboratory in Cambridge, which depended on the conditioned inhibition, were the best psychological tests developed so far. The similarity of the clinical picture in different types of stress made it highly probable that different causes of stress could be substituted for one another to an appreciable extent, and A.O.R.G. intended to use stressful peace-time training situations such as parachuting and flame warfare practice now that fighting had ceased in Korea.

12. All were agreed that it was important to know more about the extent to which one stressful situation could be substituted for another in the quantitative study of stress.

13. Mr. Mound said that he had not found it possible to produce battle fatigue in well-motivated troops even after exhausting work and prolonged lack of sleep. At the end of the period, the men were slightly better at firing weapons than at the beginning, in spite of their exhaustion. Dr. Redfearn emphasized the importance of fear in producing stress, and the fact that the fatigued man can put up a normal performance under intense motivation. Such tests as weapon firing, he continued, could not be expected to show much of a change. The fatigued pilot could read every instrument dial perfectly accurately, and his motor performance was quite unimpaired. But he did forget to look at dials which he ought to glance at occasionally, and this got worse until even the dials he ought to be looking at continually ceased to have meaning. It amounted to a progressive disorganization of the perceptual field of awareness from the periphery to the centre. Similarly, it was not motor performance so much as the meaningfulness and relevance of actions and their smooth timing relative to each other which were at first impaired. These were the most important findings of the Bartlett school.

14. Dr. Cook thought that the tests developed by the Bartlett school, and possibly tests of finger tremor, were the chief tests of practical promise at the present time in the psychological sphere. The Chairman concurred in this, and mentioned work which ORO had recently carried out at Fort Benning on men undergoing parachute training who were about to take their first leap into

space, a 34 ft. drop with no support but an overhead cable. These men were submitted to several physiological and psychophysiological tests, including a test of auditory flutter and a measure of tremor amplitude on the AORG tremor-recorder. They were measured also on the Taylor Anxiety Scale. The only scores which correlated with anxiety were tremor scores.

15. Dr. Meals confirmed this, but added that in his opinion the most fruitful line of research was to collect many observations of effective and ineffective behaviour as they occur in battle, and thus build up a composite picture of the effect of fatigue.

16. Dr. Penton said that he doubted whether such investigations had much bearing on military practice. This point was taken up warmly by other speakers with opposite views. Lt.-Col. Davies-Scourfield, however, doubted whether this type of knowledge would be of any use to an officer to whom, he maintained, knowledge and judgment about his men should become second nature through experience. Again, many of the delegates disagreed with this point of view and Mr. Gadsby achieved the compromise by saying that there was surely a certain amount of science, as well as art, in being an officer.

17. The discussion was terminated with agreement on the following conclusions:-

(a) There is a need for continuation of operational research in the realm of fatigue and stress since it offers the possibility of developing means of increasing individual and unit effectiveness.

(b) More research is needed into those factors under Army control which can alleviate stress, such as leadership, training, and combat experience, so that the relative importance of these factors, and the best way of utilizing them may be determined.

(c) More emphasis is needed in the development and testing of situations simulating combat experience, especially in view of the fact that real combat situations are no longer available for study.

(d) There is a need for the development of practical tests suitable for field use. Of particular importance is possibly the assessment of perceptual disorganization and mis-timing.

(e) Study of social or group behaviour under stress might be a profitable area for investigation.

(f) An investigation should be made into the reliability of the judgment of a commander as to the fitness of his men for action, and into the criteria used by commanders in arriving at such judgment.

(g) There should be a collection of many actual observations of the behaviour of soldiers under stress. If generalizations could be made for these data, they would be useful to the officer as a description of the symptoms of fatigue in troops, and to scientists as pointers for research.

(h) Of primary importance is the investigation of the correlation between physiological and psychological tests on the one hand, and military performance on the other.

Experimental Approach to the Assessment of Small Unit Infantry Actions

Present: Major F. G. B. Maskell, Canada. Chairman

Canada

Dr. T. W. Cook

U.S.A.

Dr. H. M. Cole

Dr. S. W. Davis

Lt.-Col. H. E. Gould

Dr. L. G. Hawkins

Brig.-Gen. S. L. A. Marshall

Lt.-Col. D. E. Munson

Dr. M. Vigneras

U.K.

Maj. W. Charlton Dewar

Maj.-Gen. B. C. Davey

Lt.-Col. D. G. Davies-Scourfield

Mr. G. N. Gadsby

Mr. P. J. Geeson

Mr. A. H. Gould

Mr. R. W. James

Mr. J. D. Oates

Mr. M. I. Rickers

Mr. H. A. Sargeaunt

Brief for Discussion

Types of Assessment

1. Small unit infantry actions might be assessed in the sense of:-

   (a) comparing various ways of performing a given tactical task (mission) in order to improve organization and tactical doctrine

   (b) comparing different troops employed in performing a given tactical task in order to improve selection and training techniques

   (c) comparing alternative weapons systems needed in the performance of a given tactical task in order to aid the development of new weapons and equipment.

2. The three types of assessment are not all independent, since the tactics adopted depend on the weapons available and on the training of the troops. Experimental material for all three consists of men.

Technical Problems

3. Solution of technical problems requires both technical and tactical knowledge:-

   (a) selection of criteria and definition of problem must be based on tactical concepts; possible criteria are achievement (e.g., ground covered), time, state of organization and control ('casualties' sustained being a special case), and tactical behaviour as scored by umpires

   (b) experimental design involves the distinction of systematic effects of various kinds from random effects, and the selection of models and appropriate statistical techniques

   (c) practical and efficient methods of recording and simulation must be developed according to the design adopted

   (d) a wider interpretation of results is required than is possible by statistical inference, which is rigorous but limited in its application, but inferences relating purely experimental results to operational effects in combat or training depend on assumption as to transferability; uncertainties might be reduced by comparative analysis of results with those of field surveys, and by insertion of experimental design into operations (either training or combat).

Organization and Administrative Problems

4. Proposals for experimentation with troops necessarily involve a statement of the probable value of the research to the Army. Balanced statements which provide sufficient basis for obtaining the necessary co-operation without compromising future co-operation by over-optimism are difficult to prepare.

5. Comprehensive research into small unit infantry action depends on the provision of permanently available resources for experimental work. This means the creation of a special organization (tactical laboratory). The insertion of experimental design into training operations is also needed, since it provides the experimenter with real situations, but the scope of such experimentation is limited and conflicting requirements of experimental control and military training must be met.

6. Some central control of research to enable questions examined in the laboratory to be efficiently introduced into training situations and battlefield surveys is necessary for progress. This may conflict with the exercise of control by local commanders under whom investigations may be carried out. A director of tactical experiments in the military organization may be necessary.

Selection of Problems for Study

7. A comprehensive programme of suitable projects is necessary to justify the creation of a special organization for experimental work. While limited investigations might be made, a long term outlook is needed in order to develop a systematic approach to the subject as a whole.

Discussion

1. There was general agreement that operational research should be concerned with the three types of assessment outlined in the brief. There were, however, some interesting differences of interest in the topic among members of the three delegations. In U.S.A., some experimental work had been begun along these lines with the object of measuring the combat preparedness of infantry squads after completion of training. This work was described, but it was explained that further development of the method was required. In particular, it was felt that although the results obtained from the subjective estimates of umpires showed high internal consistency, there was reason to doubt their absolute accuracy.

2. In U.K. no experimental work had been designed to assess small unit infantry action, but experimental work with troops was quite common, and A.O.R.G. had no difficulty in getting troops whenever they were needed. In Canada, however, there were seldom any troops available for experimental work and fully controlled experiments had not been possible. Attempts had been made to assess the content of the indoctrination training at Fort Churchill from observations made on certain northern exercises where a limited degree of control had been possible.

3. There was general agreement that small unit infantry actions can be studied only to a limited extent by the existing methods of battlefield surveys, analysis of records, and observations of training exercises. It was felt that an experimental approach is necessary in order to widen the limits of study.

4. The major problem was seen to be in the application of experimental techniques to combat conditions. It was acknowledged that validation in this sense of the term was not feasible. However, it was pointed out that all decisions made by military planners from the results of trials and exercises for application to future war were unsupported by any satisfactory system of inferential logic. Validation is possible only in actual combat, but in spite of this, interpretation of peace time experience is necessary.

5. It was also admitted that simulation of combat conditions in any general way is unlikely. It was thought, however, that satisfactory simulation in limited directions would be possible in specific instances provided that the hypotheses for test were carefully chosen. Simulation of combat stresses by exposure to a rigorous environment (such as the Canadian Subarctic) appeared to be practicable, and it was felt that further investigation would be worth while.

6. Selection of criteria must depend on the theoretical approach to the particular problem being investigated; no simple criterion for general use was suggested. Apart from the subjective estimates by umpires (see para. 1 above), two other methods of measurement had been considered and seemed to be worth further study. O.R.O. assessment of infantry soldiers in Korea was based on the performance relating to critical incidents. At Fort Churchill, Canadian workers have made assessments of the performance of marginal acts as indicators of the response to environmental stress.

7. It was accepted without question that experimental work must be closely related to operational research in combat whenever possible, both to obtain realistic experimental designs and to confirm the results of earlier experiments. In particular, it was pointed out that in war speed of analysis is important and therefore it is very desirable that peace time studies and methods of recording should be directed towards the elimination of unnecessary data collection so that matters of supreme importance can be given full attention at the outbreak of war.

8. It was agreed that problems concerned with the optimization of organization and the weapon and equipment balance of the small infantry unit require solution but are very difficult. Moreover, experimental work is time consuming, and such problems may be more easily dealt with in the first instance through the medium of models. It was felt that, at the present time, experimental work should probably be limited to simple comparisons of alternatives in connection with trends suggested by theoretical work, battlefield surveys, and other sources.

Relative Place of Guided Missiles and Guns in AA Defence

Present: Mr. I. H. Cole, Canada, Chairman

Canada

Mr. G. D. Kaye

Mr. J. E. D. McCord

U.S.A.

Mr. J. H. Henry

Mr. B. O. Marshall

Mr. A. H. Moore

Col. D. C. Tredennick

U.K.

Mr. C. L. Barham

Mr. S. W. Coppock

Mr. P. J. Geeson

Mr. A. H. Gould

Major D. Norman

Mr. G. S. Stewart

Brief for Discussion

Introduction

1. One of the most important functions of Operational Research is that of estimating the relative effectiveness of alternative new weapons. The factors to be taken into account in studies of weapon effectiveness should cover the whole field but very often quantitative information on some aspects of a problem are sparse or even lacking. Under these conditions the methods of operational research come into their own: an operational researcher, familiar with the requirements and with the particular limitations of a new equipment, may apply scientific objectiveness in separating and evaluating interacting effects, in order that the pros and cons of operationally untried weapons may be understood better.

Factors to be considered

2. A large number of factors must be taken into account before the overall index of kill potential per unit cost of a weapon system may be evaluated. The basis of cost may be monetary or in terms of "skilled men-years" of production. When quantitative data on costs or effectiveness are lacking it will be necessary to have recourse to the experience with some other known weapon.

3. An idea may be obtained from the following of the considerations to be taken into account in evaluating a weapon system:

(a) Is the weapon to be deployed in a static defence or a mobile defence: is it to defend against air raids on area targets or vital point targets

(b) Against what offensive tactics is the air defence planned: what is the expected raid strength, raid height, speed of bomber aircraft; what bomber weapons may be employed, - free-falling bombs or air-to-surface missiles

(c) Is annihilation of the bomber raids the aim of the defences or is attrition sufficient: if so, what is the desired rate of attrition

(d) Will siting difficulties of the associated radar and/or the weapon limit its useful range

(e) Evaluation of kill potential of the weapon as related to the range, rate of fire, accuracy and lethality

(f) What enemy tactics or technical counter-measures could be employed to reduce the kill potential

(g) What are the communications for alerting and co-ordinating the weapon with other forms of air defence

(h) Would the logistics of supply and maintenance present major problems: might adoption of the weapon introduce heavy demands for skilled personnel and/or a heavy commitment in training.

Simple comparison of NIKE with some AA Guns

4. A simple study has been made of the relative effectiveness of NIKE and the 90 mm AA gun in defence of a single point target. Effectiveness has been measured by the expected number of aircraft shot down by the defence when a large formation attacks the ground target in question. The attached diagram shows for various heights of attack, the number of regiments of AA guns required to produce a kill potential equal to that provided by one NIKE battalion. The target aircraft are assumed to be TU4's approaching at 300 knots and aiming free-falling bombs.

5. (a) It is seen that at fairly low heights (3,000 feet) about two regiments of 90 mm guns have the kill potential of one NIKE battalion, but that the number of regiments increases rapidly with increase in target height, till at a height of 27,000 feet some 19 regiments of guns are "equivalent" to one NIKE battalion

(b) A rough assessment of the capabilities of more advanced AA guns (such as the Vickers Interim 4" gun) suggests that these guns might be somewhat more effective, per regiment, than NIKE at low height (3,000 feet), but less effective than NIKE at heights above 10,000 feet

(c) Even at the lowest height considered here (3,000 feet) the capabilities of the acquisition radars associated with the AA guns and the NIKE system are sufficient to enable the weapons to make full use of their maximum range of action. At still lower heights the time taken for radar acquisition and tracking would be to limit the performance of both guns and NIKE, probably to about the same degree. This conjecture, however, must be confirmed by further analysis.

6. (a) Estimates of cost for the AA gun and missile systems, while necessarily tentative, suggest that a NIKE battalion will cost something between one and two times as much as a 90 mm regiment. Accepting the more pessimistic figure (for NIKE) of two, we see that on a common cost basis the 90 mm gun is about as effective as NIKE at heights of 3,000 feet, but becomes relatively much less effective as height increases, until at height 27,000 feet it is only about one tenth as effective as NIKE

(b) Cost estimates for future AA gun regiments are not available. However, if we assume that this cost is something like 1.5 times the cost of a 90 mm regiment, we find that future AA guns will be rather more effective than NIKE at height 3,000 feet and about as effective as NIKE at height 27,000 feet.

7. Other guided missiles which may come into operation somewhat later than NIKE, but before 1960 (e.g., TERRIER II, RED DUSTER, TALOS, BOMARC). These may be more effective than NIKE within their region of operation. However, some of these later missiles are expected to be ineffective at heights below 10,000 feet. In view of para. 6 (b) it appears that the later missiles may be somewhat more effective than future guns for heights above 10,000 feet.

8. (a) An increase in target speed will reduce the effectiveness of guns and of missiles probably in about the same ratio

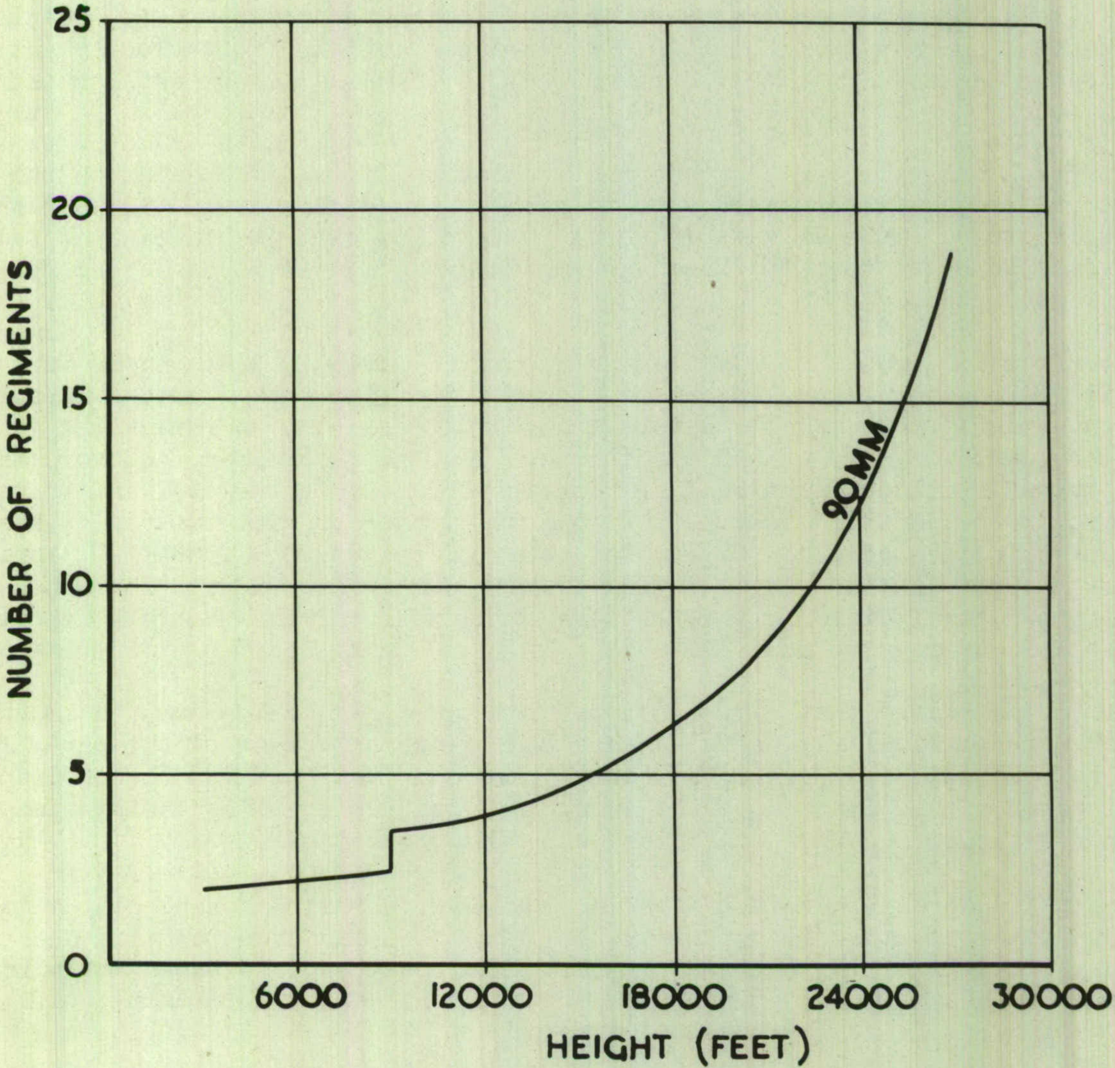
(b) Evasive action by the target aircraft will seriously reduce the effectiveness of guns, at any except the very closest ranges - but such evasive action should not have any serious effect on the accuracy of missiles

(c) Flying in formation tight enough to confuse the tracking radar will seriously reduce the effectiveness of guns and of missiles. However an obvious counter to this tactic (the use of an AA atomic head) can be implemented much more readily in the missile than in the AA gun.

9. For defence of a series of ground targets which are somewhat dispersed, or for defence against attack by air-to-surface missiles of (say) 30 to 100 miles range, the longer range of NIKE (and, even more, of the later missiles) compared with AA guns will give the missiles a decisive advantage at heights above about 10,000 feet.

10. The conclusions in this brief study are based on incomplete data and any opinion based on them is very poorly substantiated. However, they do suggest that, if guided missiles perform in operations according to expectation, they may replace guns for AA defence at all except low heights of attack. Guns might still be preferable against very low attacks - and in this case it would probably be best to use guns (such as the T212) which are designed specifically for good performance at close range.

NUMBER OF REGIMENTS OF AA GUNS REQUIRED TO PRODUCE SAME DEFENCE AS ONE NIKE BATTALION.



Discussion

1. The anticipated advantages of G.W. over guns and over fighters under certain circumstances were accepted by the meeting. It was agreed, however, that it was necessary, for the sake of clarity, to deal individually with the various uses of the weapon, and discussion was first centred on the defence of towns, centres of industry and base areas.

2. It was stated that O.R.O. had carried out studies in which the defence of towns by different weapons, including G.W. and guns, had been compared. A.O.R.G. had carried out similar comparisons, but generally without the inclusion of G.W. In general, these comparisons had been made on various grounds:-

(a) Cost/effectiveness (with sub-divisions into capital and running costs)

(b) Manpower/effectiveness

(c) Logistic load/effectiveness.

3. It was generally noted, however, that no one factor could be accepted as a measure and that under certain circumstances serious limitations might be imposed by certain critical shortages (e.g., of materials or skills) or by such factors as excessive vulnerability.

4. It was also made clear that the studies so far made depended on the assumptions made with regard both to attack and to defence tactics and that these features would inevitably change materially with the passage of time. It was also noted that the basic assumptions might well be different for the three countries.

5. A certain amount of work had been carried out by O.R.O. on the more mobile forms of defence, and there was an indication that a guided missile defence might prove more lethal to enemy attackers than an equivalent gun defence would be under field conditions. It was recognized, however, that the types of attack might be different from those on towns etc. and that the object of the defence might be more one of beating off attacks (or at least of upsetting the accuracy of bombing) than of destroying aircraft. Furthermore, the difficulties of achieving adequate control of identification facilities under field army conditions might well prevent the full use of the range and coverage of the G.W.

6. It was stated that O.R.O. had carried out some machine computations which were particularly useful when a wide range of values of the parameters had to be considered (e.g., the actual values of the V.As and the positions of the weapon sites with respect to specific V.As., reliability factors for the weapon systems, and the accuracies achieved by the missiles).

7. It was agreed that it was often necessary, both in machine computations and in other methods of comparison, to make broad and often unconfirmed assumptions about missile performance. The results would necessarily have to be used with caution. It was thought, however, that an approach would gradually be made to the correct answer.

8. The reliability of highly complicated guided weapons was discussed, and it was emphasized that these defences were yet in their early stages; the extreme reliability of modern electronic computers was cited as an example of the results which might be expected in a few years.

The effects of Signal Communications on Military Operations

Present: Dr. Thornton Page, U.S.A. Chairman

Canada

Mr. T. K. Groves

Mr. G. D. Kaye

Major J. S. Orton

U.S.A.

Dr. G. Gamow

Dr. J. B. Green

Mr. B. O. Marshall

Dr. E. W. Paxson

Dr. L. H. Rumbaugh

Dr. J. K. Tyson

U.K.

Mr. R. W. Brittain

Mr. B. D. Hankin

Mr. W. H. Hill

Major M. P. King

Lt.-Colonel V. H. B. Macklen

Mr. F. J. Nash

Mr. A. W. Ross

Mr. H. A. Sargeaunt

Dr. I. J. Shaw

Mr. G. Wooldridge

Brief for Discussion

INTRODUCTION

Military operations may be thought of as the controlled application of force on the enemy in accordance with the requirements of a mission imposed by a higher authority and in relation to the best available intelligence of the enemy and the environment. Much is made of the advantages enjoyed by the military force which has communications facilities superior to those of enemy. In what ways is the success of military operations influenced by signals communications?

Signal communications make operational control possible by providing links to (1) carry orders from commanders to subordinates and return to the commander the feed-back of acknowledgment and for reports of the results of action (2) bring information of the enemy and the environment to friendly filter and interpretation centres and return to collection agencies the feed-back of new information requirements. See Fig. 1. The basic functions supported by signal communications, then, are sensing or information gathering; decision-making and reacting.

Speed and accuracy are the characteristics of signal communications systems which are normally considered to influence these functions most directly. A more complete statement of these characteristics is as follows:-

(1) Maximum information-handling rate.

(2) Averaged information-handling capacity.

(3) Accuracy or distortion.

(4) Cost (a) dollars (equipment and re-supply)

(b) maintenance and operation (manpower and training required)

(c) bandwidth required (either radio frequency in air or appropriate ground line necessary).

The distinction between items (1) and (2) is based on the assumption that a given electronic signal communication link may have a high information-handling rate but may not maintain this rate because of countermeasures or noise fluctuations. Or, a messenger can carry a great deal of information at a high instantaneous rate but a very low averaged rate. In general, it is the averaged rate which most directly determines the adequacy of the communication link for a given function. Item (3) is self evident but should always be related to the appropriate accuracy criterion for the military task at hand. Item (4) will not be discussed in this paper.

Perhaps the simplest military model which illustrates the relationship of signal communications characteristics to the information-gathering, decision-making and action functions of military operations is a complete gunfire control system. In such a system the sequence of operations is (a) target detection (b) target tracking (c) target evaluation (d) decision to attack (e) gun-pointing and firing orders (f) error-sensing and corrections.

It is axiomatic that for a given task there is an optimum information requirement with respect to the rate and total amount of information as well as the type. For example, any delays or errors which occur in steps (a) or (b) or in the transfer of data to (c) can seriously reduce the effectiveness of the whole system. However, if the target's velocity is low enough relative to the speed of the action processes (c) through (f), and if the errors are small, and if tracking continues long enough and provides enough data to permit prediction of the target's future position then successful action is still possible.

As the delay involved in steps (c) through (e) increases, so too must the

length of the extrapolated target path increase to permit effective fire.

The information-gathering, decision-making, and reacting functions referred to earlier all require finite amounts of time which vary, respectively, with detection probabilities, the number of possible alternatives, and the size of the force involved. These built-in, and generally irreducible delay times, in military operations impose stringent requirements on the supporting signal communication system for maximum information transfer rate and minimum error or distortion.

In any foreseeable future conflict, the known large capabilities of our potential enemy in the fields of radio direction-finding and jamming may seriously reduce the averaged rate of information transfer by electronic means. On the other hand the threat of tactical atomic weapons urge us to develop tactics for which high-speed, long range communications will be more necessary than ever since our forces will be dispersed in smaller units over larger areas. In the light of the generalized military operations functions outlined earlier and the characteristics of signal communications what are some possibilities for resolving this conflict?

PROPOSITIONS

1. Communications needs are usually reduced whenever redundancy increases. In terms of military operations, the more action alternatives the commander at any echelon has recognized and prepared for in advance, the less communication time is required in form of reports from subordinates and orders from the commander. Thus, for the contingencies of atomic warfare, the division commander, for example, should call for operational plans which extend two or three times farther into the future than is the case for conventional tactics. The mission and specific objectives should be explained in detail to all unit commanders in the division down to the battalion level and time should be allowed for a final briefing for all unit commanders of every unit's operations plan. While this would be a difficult and time-consuming activity, it would greatly increase the redundancy level for each commander and with uncertainty reduced, less communication would be required to accomplish the overall mission. Techniques of this kind have been used in the WW II in operations planning for airborne divisions.

2. A communication channel full of information about enemy and friendly forces makes precise planning possible and minimizes errors but also is vulnerable to enemy countermeasures in proportion to time on the air. In addition, the average information transfer rate may be slow. All combat information intended for electronic transmission should be stored and compressed at each transmission point and released in short, high-energy bursts rather than by CW or in some regularly modulated manner. The lengths of intervals between bursts should be varied randomly within certain limits or should be preplanned in schedule which is securely encrypted when announced for a given period. The combination of short, high-energy pulsed transmissions and irregular times of transmission should reduce the probability of enemy countermeasures.

3. The most serious single cause of delay, error and distortion in signal communications when the traffic load is heavy is the human operator. Where simple operations such as those performed by a transponder or retransmitter are required the use of human links must be minimized. In general, the probability of error, distortion or delay in a signal communication system increases exponentially with the number of links in a sequence from the sender to the receiver of a message.

4. To conserve radio frequency spectrum, larger nets must be designed with more "subscribers". Telephone part-line techniques or those used in naval sound-powered system can be adapted to provide for both scheduled and flash urgent use of the nets. Large amounts of data can be handled in this way with minimum bandwidth cost and little or no loss in operational effectiveness if proper discipline and effective information-coding (not encrypting) are employed.

5. Encrypting and decrypting operations are among the worst time-consumers and potential error-producers in signals communication. Aside from high-speed, on-line automatic encrypting and decrypting machinery, the use of the compressed, stored, high-energy-pulsed transmission system mentioned earlier would provide for a large proportion of security needs.

6. The use of airborne (balloon) high-powered relaying transmitters should be considered to increase the effective ranges obtainable with UHF equipment and to make possible multiple address message sending from lower to higher echelons.

7. Training exercises should begin immediately to teach friendly forces to develop and exploit all non-electronic communications methods now known and to see others. As a counter intelligence measure and to deal with enemy jamming, all friendly forces should attempt exercises and manoevers in which one side is equipped with the full complement of modern signal equipment while the other is denied even the telephone. The time-constants in non-electronic communication methods are not necessarily too long for effective military operations with atomic weapons. The use of lights, bugles, pulsed earth shocks, smoke and other techniques can adequately handle the signal communications requirements of a modern army with proper planning.

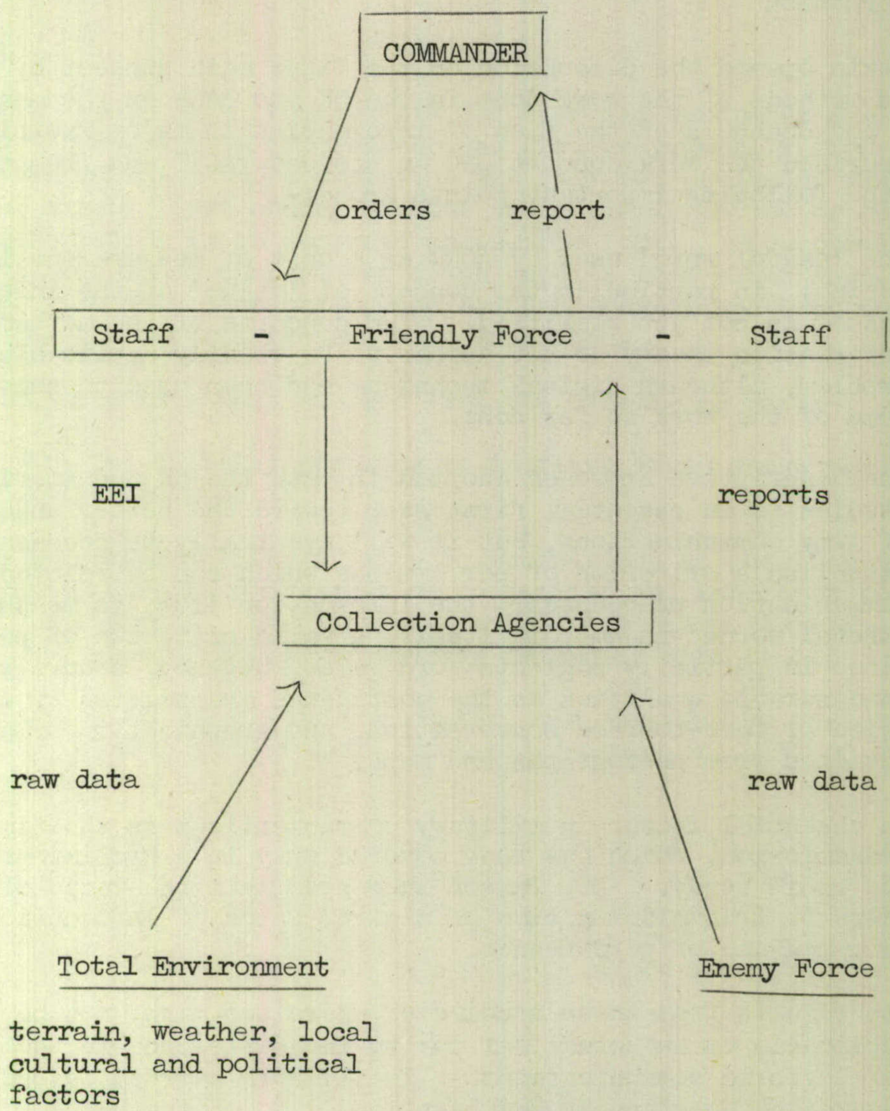
8. Intensive study is required of the basic amounts, rates, and kinds of information required for a variety of military operations. Only when appropriate data concerning these requirements are available will it be possible to design optimum signal communication systems in terms of the parameters mentioned earlier. It may be that a large fraction of the total amount of combat data now encoded (not encrypted) in language and transmitted orally or in writing may better be handled as pulse-coded symbols requiring far less bandwidth than is now necessary.

9. Signal communications officers should function with G-3 as staff planners in the design of military operations and should give close attention to the possibility of redesign of military tactics to fit special communications problems.

FIGURE 1

Schematic diagram of essential information-carrying links within an echelon

and the classes of information carried



procedures had been developed from just such experience. There was a measure of agreement with Dr. Paxson's suggestion that Army communications must be good enough not to be the limiting factor in land combat.

9. The following conclusions and recommendations were agreed:-

(a) The descriptive studies in progress at AORG and ORO promise a fuller understanding of the communications problem; they should be extended to include urgency, security and the concept of value and should be related to a criterion of military performance.

(b) Exercises under controlled conditions should yield fruitful comparisons between different communications systems on which improvements might be based. In particular the British PHANTOM system should be compared with conventional systems.

(c) The increased complexity of communications equipment should be kept under constant review. The relation between causes of failure, delays and the consequent effects on operations need study. In addition, a cost-effectiveness comparison between sub-assembly replacement techniques and existing maintenance methods should be made.

(d) An assessment should be made of the vulnerability of existing means of communication. In particular, military exercises should be held where the use of wire and radio is restricted or even prohibited, to see what can be done to control formations under such conditions.

(e) The time factor in the overall transmission and processing of military information is extremely important. Further study is required to find out how far this time is the limiting factor in the control and mobility of fighting forces.

(f) At Divisional level, personal contact is capable of handling a very large part of the military information needed for control. Means should be sought to exploit this system.

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